U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

TRECOM TECHNICAL REPORT 63-64

FLEXIBLE-WING PRECISION DROP GLIDER

FINAL REPORT

Task 1D121401A14172
(Formerly Task 9R38-01-017-72)
Contract DA 44-177-AMC-875(T)

December 1963

prepared by:

RYAN AERONAUTICAL COMPANY
San Diego, California

sponsored by:

THE ADVANCED RESEARCH PROJECTS AGENCY

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HEADQUARTERS
U S ARMY TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS. VIRGINIA 23604

This report was prepared by Ryan Aeronautical Company in accordance with the requirements of Contract DA 44-177-AMC-875(T) initiated by the U.S. Army Transportation Research Command, Fort Eustis, Virginia, and funded by the Advanced Research Projects Agency, Washington, D.C.

The conclusions reached in this report are concurred in by this command. Based on these conclusions, a follow-on program of demonstrations of the Precision Drop Glider (PDG) has been conducted.

Since this program has demonstrated the feasibility of the PDG for use as a highly accurate aerial delivery system, it is concluded that immediate development of a 500-pound-payload Precision Drop Glider is practical.

This command gratefully acknowledges the counsel and assistance provided during this project by the Airborne Test Activity, Yuma Proving Ground, Arizona, and the National Aeronautics and Space Administration, Langley Research Center.

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Task 1D121401A14172
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Prepared by
RYAN AERONAUTICAL COMPANY
SAN DIEGO, CALIFORNIA
Report No. 63B011

for
U. S. ARMY TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA 23604

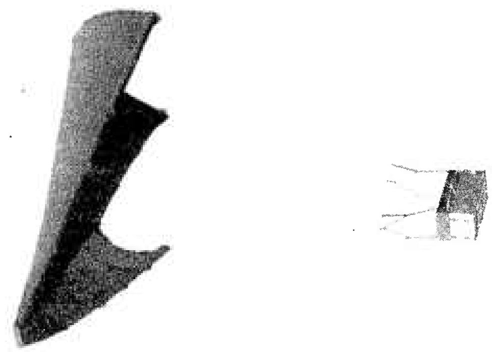


Figure 1 Precision Drop Glider in Flight

PREFACE

The design, fabrication, and test program covered by this report was conducted by the Ryan Aeronautical Company, under provisions of Contract DA 44-177-AMC. 875 (T), awarded to the Ryan Aeronautical Company by the U. S. Army Transportation Research Command and funded by the Advanced Research Projects Agency.

Design, analysis, and fabrication were accomplished at the contractor's plant, San Diego, California.

All testing was conducted at the Yuma Test Station, Yuma, Arizona, between 4 October 1962 and 1 March 1963. The Airborne Test Activity at the Yuma Test Station provided aircraft support, range and theodolite facilities, and hangar work space.

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Cont'd)

ILLUSTRATIONS (Cont'd)

SYMBOLS

A	Area, ft^2
b	Flatplan wing span, ft
C_D	Drag coefficient, $\frac{D}{qS}$
C_{D_B}	Drag coefficient associated with suspended body
C_{D_O}	Drag coefficient associated with parachute
C_L	Lift coefficient, $\frac{L}{qS}$
C_ℓ	Rolling moment coefficient, $\frac{L_r'}{q\,Sb_{F.P.}}$
C_m	Pitching moment coefficient, $\frac{M}{qSc}$
C_n	Yawing moment coefficient, $\frac{N}{qSb}$
c	Factor related to suspension line convergence angle. For suspension line lengths approximately equal to parachute diameter, $c = 1.055$.
c.g.	Center of gravity
c.p.	Center of pressure
C	Section chord, ft
c	Keel length, ft
c	Distance to outer fiber, ft
D	Drag force parallel to flight path $C_D qS$, lb.

D	Diameter, ft.
D_o	Largest inscribed diameter of circular parachute, ft.
d	Distance from c. g. of canopy to suspension point on the load, ft.
e	Factor related to strength loss by abrasion
F	Force, lb.
F_o	Opening shock force, lb.
F_{tu}	Ultimate tensile stress, lb/in^2
f_b	Bending stress, lb/in^2
f_t	Tension stress, lb/in^2
G. W.	Gross weight, lb.
g	Acceleration of gravity, 32.17 ft/sec^2
h	Altitude, ft.
h_o	Launch altitude, ft.
h_s	Launch altitude, ft.
I	Moment of inertia, $inches^4$
j	Safety factor equals 1, 5 for aerial delivery of cargo
k	Opening shock factor
k	Factor related to strength loss by fatigue equal to 0.95
K_b	Drag loading of suspended body, ft^{-1}

K_p	Drag loading of parachute, ft^{-1}
L'_r	Rolling moment
l	Length of member or line, ft.
l	Distance, ft.
l_s	Launch line length, ft.
l_c	Parachute plus suspension line length, ft.
m	Mass, slug
M	Bending moment,
M	Pitching moment, $C_m qSc$
N_h	Hoop load per foot of width, lb/ft^2
N	Normal force, lb.
N_o	Required strength per unit length, lb/in.
N	Yawing moment
n	Ratio of parachute and body drag loading
n	Load factor
o	Factor related to strength loss in material from water and water vapor absorption.
P	Load, lb.
P_{max}	Breaking strength of suspension line, lb.
p	Wing load, $\frac{n_z W}{S}$, $lb/ft.^2$

p	Pressure, lb/ft.^{2}, lb/in.^{2}
q	Dynamic pressure, $\frac{1}{2}\rho V^2$, lb/ft^2
R	Gas constant, ft-lb/lb - R^o
R	Radius of wing membrane, ft.
R	Radius of inflatable tubes, ft.
S	Flatplan wing area or reference area, ft.^{2}
S_B	Suspended body area w/r to drag, ft.^{2}
S_o	Reefed parachute drag area w/r to drag, ft.^{2}
S_u	Uninflated parachute drag area w/r to drag, ft.^{2}
t	Time
t_d	Deployment time, second
t_f	Parachute filling time, second
t	Thickness, inches
u	Factor involving the strength loss at the connection of suspension line and drag producing surface.
V	Free stream velocity, ft/sec. or knots
V	Volume, ft.^{3}
V_o	Launch velocity, ft/sec
V_s	Velocity just prior to parachute filling, ft/sec.
W=Wt	Weight. lb

$W_t = W_B$	Suspended weight, lb.
W_p	Parachute weight, lb.
x	Longitudinal distance, ft.
y	Lateral distance, ft.
y	Distributed load, lb/ft
Z	Number of suspension lines
a, α	Angle of attack, degrees
γ	Flight path angle from horizon, degrees
γ	Specific weight of air, sea level, lb/ft^3
ϵ	Angle between the wing resultant force and a normal to the plane of the leading edge members.
ϵ_{max}	Maximum elongation of suspension line, ft. (approx. 30%)
θ	Wing pitch attitude, degrees
Δ	Leading edge sweep angle, degrees
ρ	Mass density of air, $slugs/ft.^3$
σ_L	Longitudinal membrane stress

TABLES

SUMMARY

The objective of this program was to establish the feasibility of the flexible-wing paraglider concept as a means of controlled cargo delivery from either fixed-wing aircraft or rotary-wing aircraft to a predetermined landing site. Full-scale inflatable wings and control platforms were designed, fabricated, and flight tested to demonstrate this feasibility.

Specific areas of investigation included packing methods, launch techniques, deployment, transition from the parachute mode into the wing, controllability, glider performance, ground station manual control techniques, and automatic-home control evaluation.

Considerable testing was directed toward determining the optimum packing method and deployment technique in an effort to achieve system reliability and toward effective system control in an effort to achieve minimum circular-error-probability.

The feasibility of using the flexible-wing glider as a controllable means for cargo delivery to a predetermined landing site was successfully demonstrated. A flight envelope, encompassing allowable limits of airspeed, altitude and payload, has been established for the final configuration of the series.

CONCLUSIONS

As a result of the flight tests conducted during this program, the following conclusions are drawn:

AERODYNAMICS AND PERFORMANCE

1. The feasibility of using an inflatable flexible wing as a controllable air cargo delivery system has been demonstrated.

2. Satisfactory flight control response to discrete manual command inputs was demonstrated during the flight test portion of the program. Limited success was achieved while utilizing the automatic-home mode of operation.

3. The radius of a 360-degree turn usually varied between 200 and 400 feet at an average glide ratio of 2.8:1. The usual loss in altitude during one 360-degree turn was between 100 and 300 feet. The average forward velocity was 38.8 feet per second, or 23 knots, TAS, (True Air Speed).

4. The maximum and minimum rates of descent for the PDG varied between 600 and 900 feet per minute for payloads ranging from 100 to 300 pounds. The average rate of descent was 800 feet per minute.

5. The theoretical wing size selection in relation to glide slope and velocities was verified by data accumulated throughout the flight test portion of the program.

6. Since no airborne instrumentation was used, landing impact loads were not measured; but normal landings, with a fully developed wing, did not cause any damage to the cardboard cargo containers.

STRUCTURAL CRITERIA AND LOADS

A structural investigation program was conducted within the overall flight test program to obtain data from drops up to a pressure altitude of 9,000 feet. The structural envelope for the opening shock loads of the paraglider was determined by means of establishing the upper limits of airspeed and payload weights within which structural failure was absent. For high-wing, single-engine, and for

high-wing, multi-engine, rear-exiting aircraft, the launch conditions were different from those of low-wing, multi-engine aircraft because of prop-wash and down-wash effects. The maximum allowable payloads were determined to be:

U-1A, U-6A, AC-1, etc.		C-47	
Calibrated Airspeed, Knots	Max. Allowable Payload Weight, Pounds	Calibrated Airspeed, Knots	Max. Allowable Payload Weight, Pounds
85	300		
90	250	90	200
95	200		

DESIGN

1. The initial wing design with modifications proved to be an acceptable system for operational feasibility evaluation.

2. The parachute phase was most critical for system loading, and the transition phase from parachute to wing was most critical for overall system reliability.

3. The load distribution through the gussets to the membrane attachments provided a uniform stress distribution into the basic fibers of of the material.

4. Simultaneous release of the forward and aft parachute line latches during the transition phase from the parachute mode into the glider mode is essential.

5. Suspension line stow loops for all parachute and glider lines should be included in the manufacture of an operational production paraglider.

FLIGHT TEST

1. The opening parachute shock loads during paraglider deployment at 95 KCAS are marginal at suspended gross weights in excess of 330 pounds.

2. Equilibrium rates of descent and yaw rates are as predicted. Radius of turn and glide ratio characteristics are satisfactory.

3. Ejection techniques which involve significant tumbling introduce an increase in probability of line entanglement during paraglider deployment.

4. The auto-homing system demonstrated satisfactory convergent yaw oscillations in the homing mode.

5. Landing impact loads and velocities in the normal glider mode produced no appreciable damage to the payload. On those landings during which tumbling of the payload occurred upon landing, only superficial damage to the cardboard container was observed. The rate of descent associated with this final configuration is approximately 800 feet per minute.

RECOMMENDATIONS

As a result of the satisfactory feasibility demonstration of the Precision Drop Glider, these requirements have been formulated for improving the present flight article with a view toward the ultimate tactical flexible-wing cargo delivery system. It is therefore recommended that the following be incorporated in the development phase of a flexible -wing paraglider.

I. Material Research and Testing:

A. Evaluate new materials and adhesives (inflatable section)

1. Material optimization

a. Minimum base cloth weight

b. Minimum coating

c. Fabric flexibility

d. High strength

e. Tear and notch resistance

f. Abrasion resistance

g. Crease resistance

h. High energy absorption

i. Non-porosity

j. Shelf life

2. Adhesive optimization

a. Unlimited shelf life

b. Single pot adhesive

c. Material/coating compatibility

d. High strength

e. Ease of application

B. Evaluate new materials, adhesives (membrane) and optimization:

1. Non-porous

a. Minimum base cloth weight

b. Minimum coating

c. Fabric flexibility

d. High strength

e. Tear and notch resistance

f. Abrasion resistance

g. Crease resistance

h. High energy absorption

2. Porous

a. Minimum cloth weight

b. High strength

c. Tear and notch resistance

d. Abrasion resistance

e. Crease resistance

f. High energy absorption

3. Adhesive Optimization

a. Unlimited shelf life

b. Single adhesiveness

c. Material/coating compatibility

d. High strength

e. Ease of application

II. Pneumatic System Investigation

A. Air bottle versus gas generator

1. Parametric study entailing;
(Continued)

a. Inflatable volume

b. Minimum inflation time

c. System weight

d. Recharge capability

e. Shelf life

f. Reliability

g. Compatibility of gas with fabric and adhesive

B. Reliability

1. Tube section

2. Inner linings of secondary tubes

III. Prototype Design

A. Scale effect

1. Keel length greater than 22 feet

2. Keel length less than 22 feet

B. Configuration evaluation

1. Inflatable tubes

a. Diameter

b. Wall thickness

c. Camber

(1) Leading edge

(2) Keel

d. Aerodynamic fairing

e. Method of attaching to membrane

2. Membrane

a. Scalloped trailing edge

b. Shaped

c. Non-porous

d. Porous

3. Line attachments, number and location (load distribution)

    a. Leading edge

    b. Keel

4. Redundancy within the tube member section.

IV. Fabrication of Test Articles

V. Instrumentation of Test Articles

VI. Wind Tunnel - Tower - Aircraft Tests

A. Structure

1. Determine membrane stresses.
2. Determine tube stresses.
3. Porous versus nonporous membrane opening shock loads.
4. Parachute and wing shroud line loads.
5. Optimize pack methods to alleviate opening shock loads.
6. Increase payload, airspeed, altitude launch envelope.

B. Deployment

1. Static line/sleeve
2. Static line/deployment bag
3. Static line/sleeve/extreme forward c.g.
4. Sleeve/pilot chute

C. Transition

1. Extreme forward c.g. (ballistic path) investigation to eliminate parachute completely
2. Tow inflated wing
3. Shroud line stowage

D. Aerodynamics

1. Inflatable tubes

    a. Diameter

    b. Fairing

c. Camber

(1) Leading edge

(2) Keel

2. Membrane

a. Scalloped trailing edge

b. Shaped

c. Porous

d. Non-porous

3. Performance optimization

a. Angle of attack

b. Wing shape

c. Glide ratio

d. Rate of turn

e. Close-in-characteristics from flight control response

E. Flight Control

1. All-weather, all-climate radio control system

2. Homing system compatibility with optimum flight path

3. Control system

4. Center of gravity shift

5. Aileron

INTRODUCTION

A number of theoretical and experimental investigations have been conducted to determine the feasibility of using the Rogallo paraglider wing as a delivery system for various payloads under various environmental conditions.

One such application is the use of a paraglider as a means for airborne cargo delivery. Such an application requires a wing with flexible structural members, which would enable the wing to be folded and packed. Consequently, in addition to satisfactory performance and flying characteristics, operational feasibility is dependent upon a reliable packing and deployment sequence.

Normally, under combat conditions, a relatively low percentage of the air-dropped supplies are recovered by the personnel for whom they are intended. The air cargo delivery application, as discussed in this report, offers in addition to present advantages of parachute delivery, the highly desirable advantages of an offset cargo launch point and the capability of homing in to a precise position on the ground during high wind conditions, low overcast, or at night; hence the name Precision Drop Glider (PDG).

Prior to this program, a 10-foot scale model of an inflatable wing was built and tested by the Ryan Aeronautical Company. The results of those tests showed that an inflatable wing does have favorable flying qualities and can be packed and successfully deployed. An earlier test program (see Reference 2), which utilized almost the identical inflatable wing configuration and launching techniques as discussed in this report, was conducted with success prior to initiation of the PDG test program.

The tests covered in this report were undertaken to establish system feasibility, using a full-scale wing and payload. Primary areas of interest during the test program were packing and deployment, performance, and flight control response from manual ground command inputs or from auto-homing.

DISCUSSION

AERODYNAMICS AND PERFORMANCE

This section contains aerodynamic characteristics and performance data Figures 2, 3 and 4 supplemental to Ryan Report No. 62B074 (Reference 1). In addition to these data, portions of the aerodynamic data from the abovementioned report have been included as a basis for comparison and to make this section usable without continuous reference to Report 62B074.

The performance data presented in Reference 1, Figure 5 and 6, were based on the payload's being suspended 75 percent of the keel length below the wing, and the glider was designed utilizing this vertical attach distance. The selection of the 75 percent keel length is a compromise between the leading edge compressive forces of a short suspension system and the increased drag created by a longer suspension system.

The longitudinal c. g. positions required to trim the glider with a vertical attach distance of 0.75 keel length were calculated from an equation representing a moment summation about the c. g. These curves were utilized to develop the general arrangement and rigging drawing, (Ryan Drawing No. 149-B-001).

Glide performance for standard and hot-day conditions is based on glide at an angle of attack of 30 degrees except for rates of descent, which were calculated as a function of angle of attack, Figure 7, 8, and 9.

STRUCTURAL CRITERIA AND LOADS

The structural design of the paraglider is based upon the loads developed during all phases of the system operation. In addition to the loading requirements, consideration must be given to the problems of packaging, environment, and deployment. The design constraints on the wing construction are determined from the operating environment and cargo force and acceleration limitations. These constraints are:

1. Material used in the wing must be flexible and lightweight. It must retain essential properties during environmental conditions that can be expected during field operations. It must be capable of being stored folded for extended periods of time.

2. Packaging of the paraglider must be done with consideration of the capabilities of the fully loaded airborne cargo container. A package size approaching that of the present T-10 parachute is desirable.

3. The weight of the system shall be kept to a minimum.

4. The construction shall allow for folding consistent with sound deployment procedures.

5. Accelerations encountered during deployment shall be within acceptable cargo tolerances.

6. A factor of safety of 1.50 will be observed for all conditions and for all components.

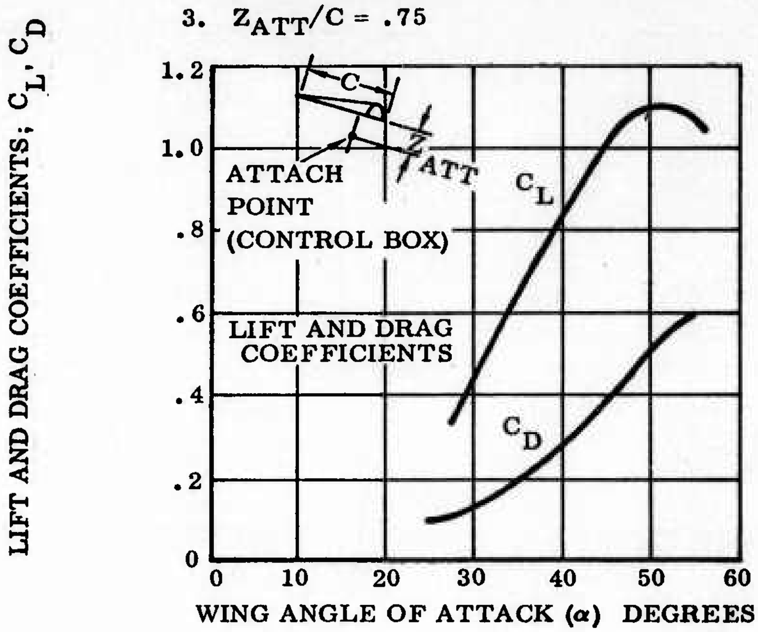
The critical load factor experienced by the paraglider system occurs during the deployment sequence. The system shall be designed for the following conditions during deployment.

Total Weight	425 lbs. @ 85 kts CAS 325 lbs. @ 95 kts CAS
Suspended Weight	375 lbs. @ 85 kts CAS 275 lbs. @ 95 kts CAS
Payload Weight	300 lbs. @ 85 kts CAS 200 lbs. @ 95 kts CAS
Design Limit Load Factor (n_{o_1})	5.7 g limit 85 kts CAS
(n_{o_2})	8.79 g limit 95 kts CAS

The design limit load factor occurs during opening shock of the wing while reefed as a parachute. The theoretical procedures employed in the analysis are patterned after the methods outlined in WADC-TR-55-265.

NOTE:

1. C_L, C_D, AND L/D ARE FOR WING ONLY
2. C_L AND C_D ARE BASED ON FLATPLAN WING AREA (277.6 FT.^{2})
3. $Z_{ATT}/C = .75$



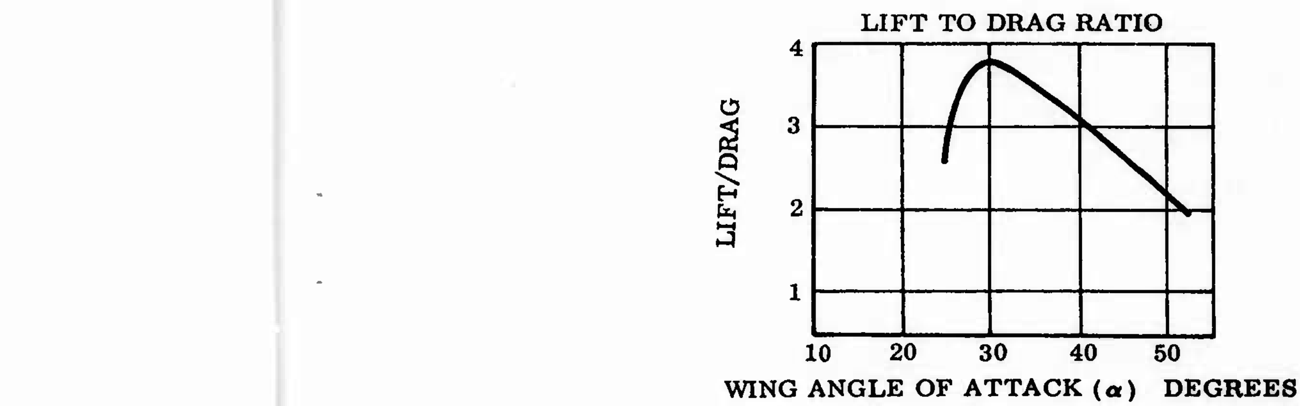


Figure 2 Theoretical Wing Aerodynamic Characteristics

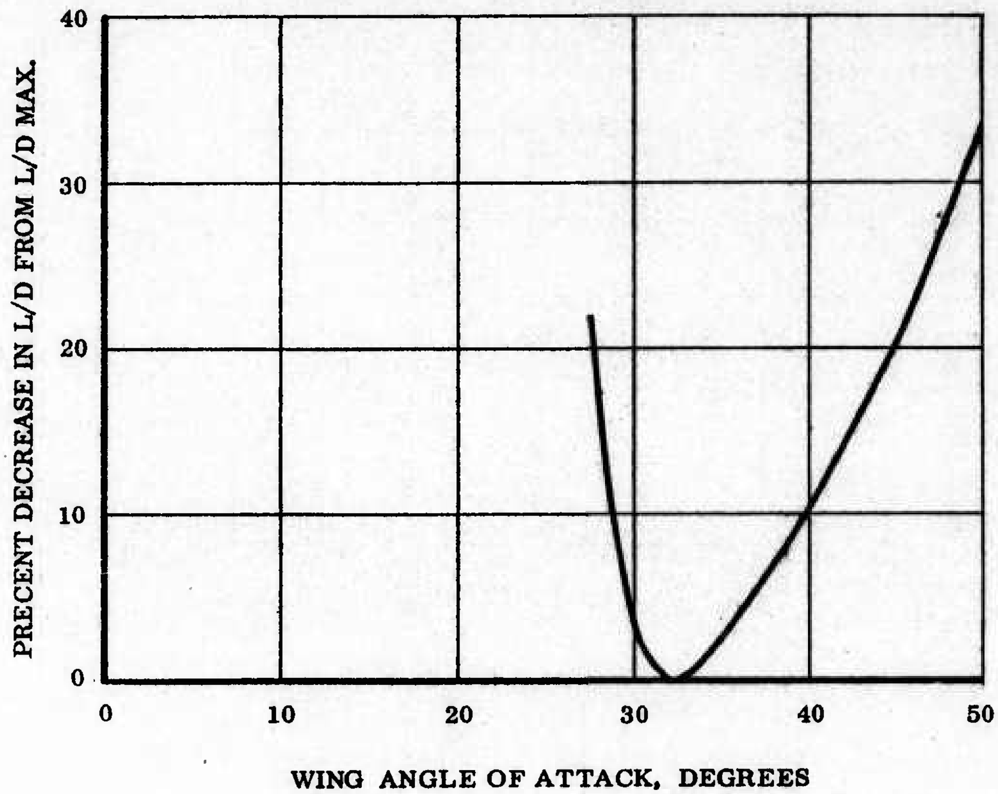


Figure 3 Theoretical L/D Penalty for Complete System at Angles of Attack Other than for L/D_{max}

NOTE:

1. $Z_{ATT}/C = .75$

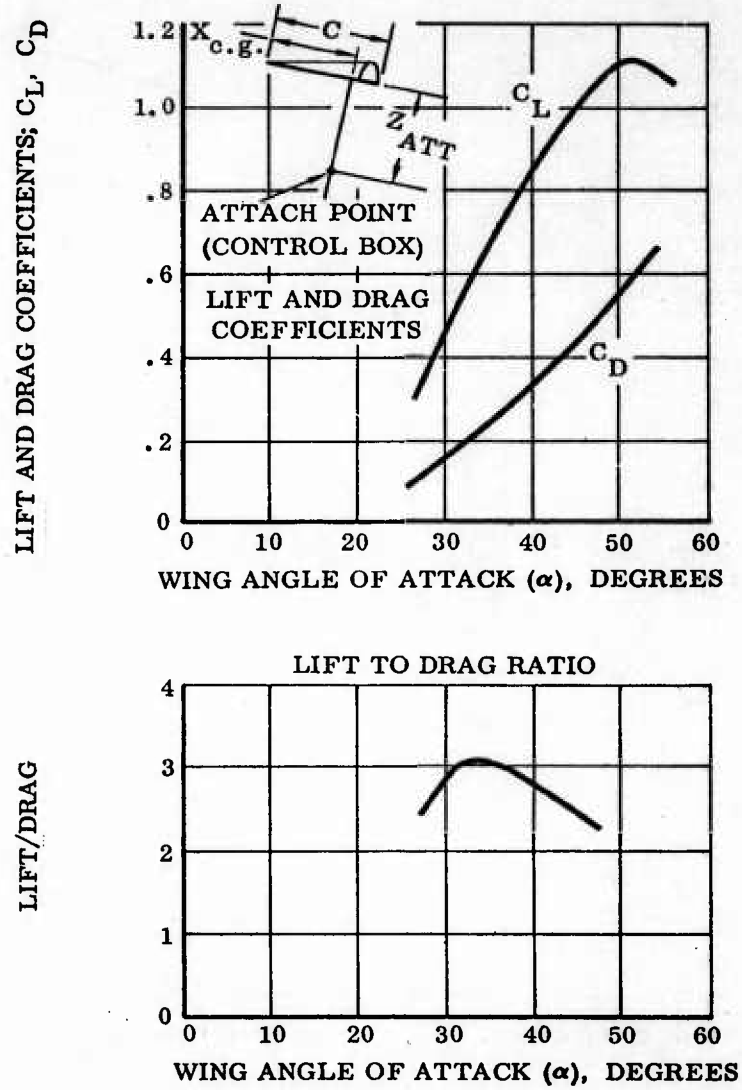


Figure 4 Theoretical Aerodynamics of the Complete System

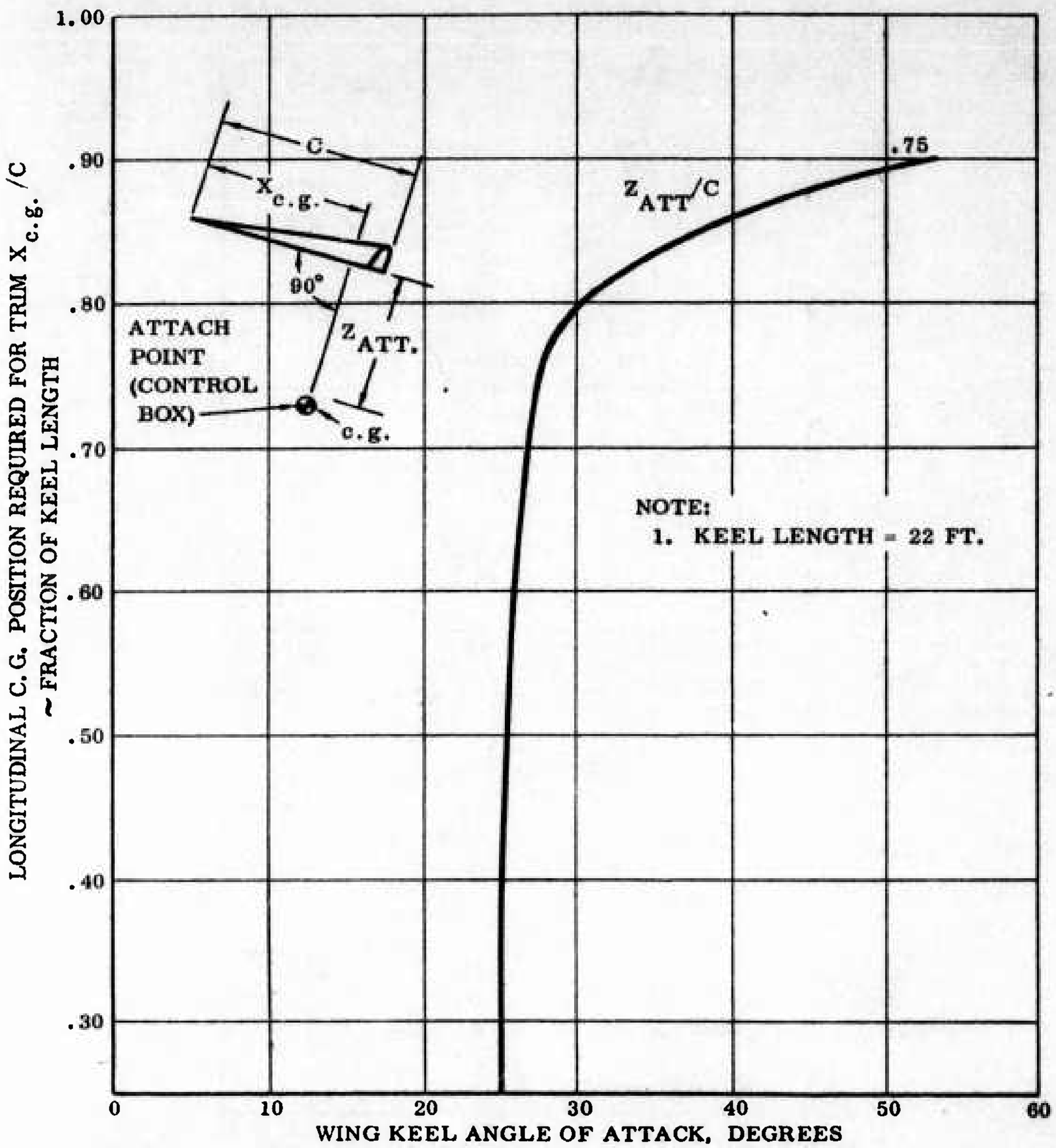


Figure 5 Theoretical Longitudinal C.G. Position Required for Trim

THEORETICAL LONGITUDINAL C. P. POSITION
AND ANGLE OF RESULTANT FORCE

NOTE:

1. $Z_{ATT}/C = .75$
2. FLATPLAN SWEEP = 55°
3. BASED ON RYAN WIND TUNNEL TESTS
4. CENTER OF PRESSURE - C. P.

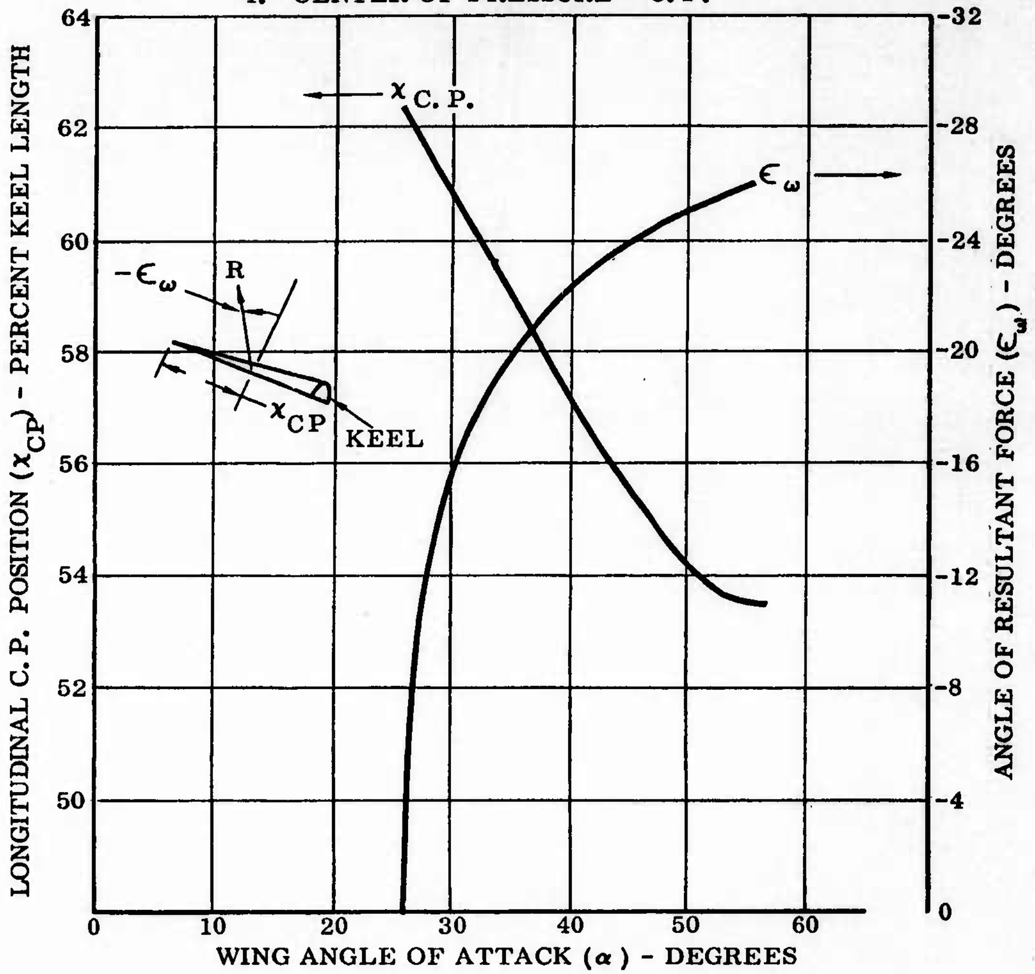


Figure 6 Theoretical Longitudinal C. P. Position and Angle of Resultant Force

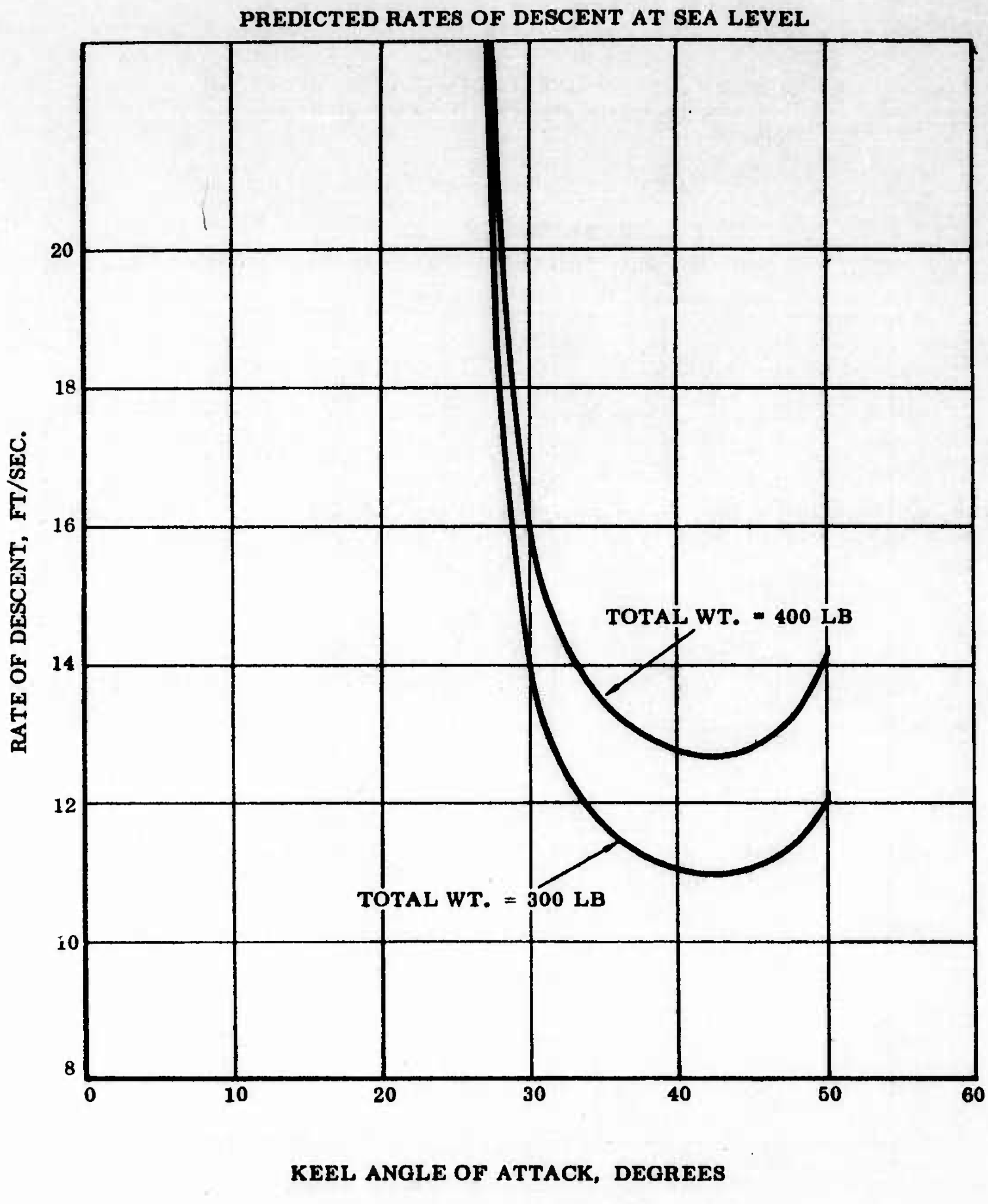


Figure 7 Predicted Rates of Descent at Sea Level

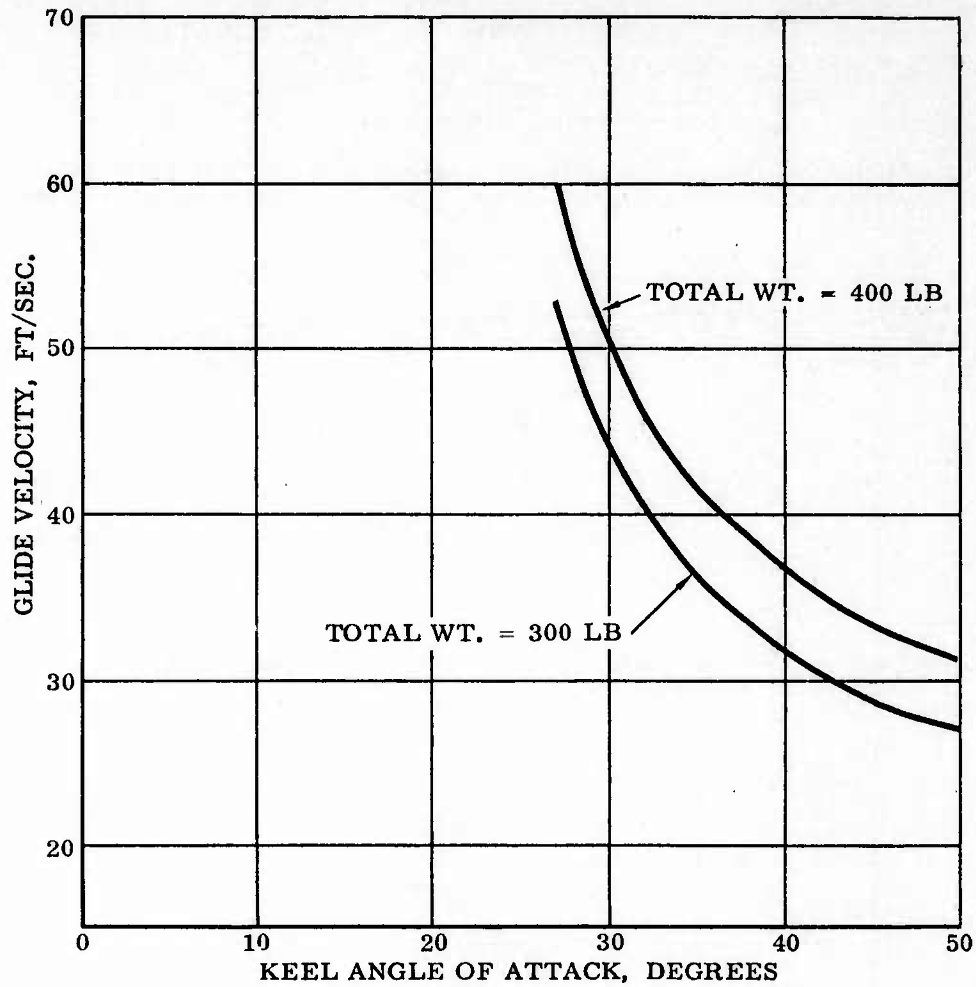


Figure 8 Predicted Glide Velocity at Sea Level

NOTE:

1. ANGLE OF ATTACK = 30°
2. NO WIND
3. APPLICABLE TO STD. OR HOT DAY CONDITIONS

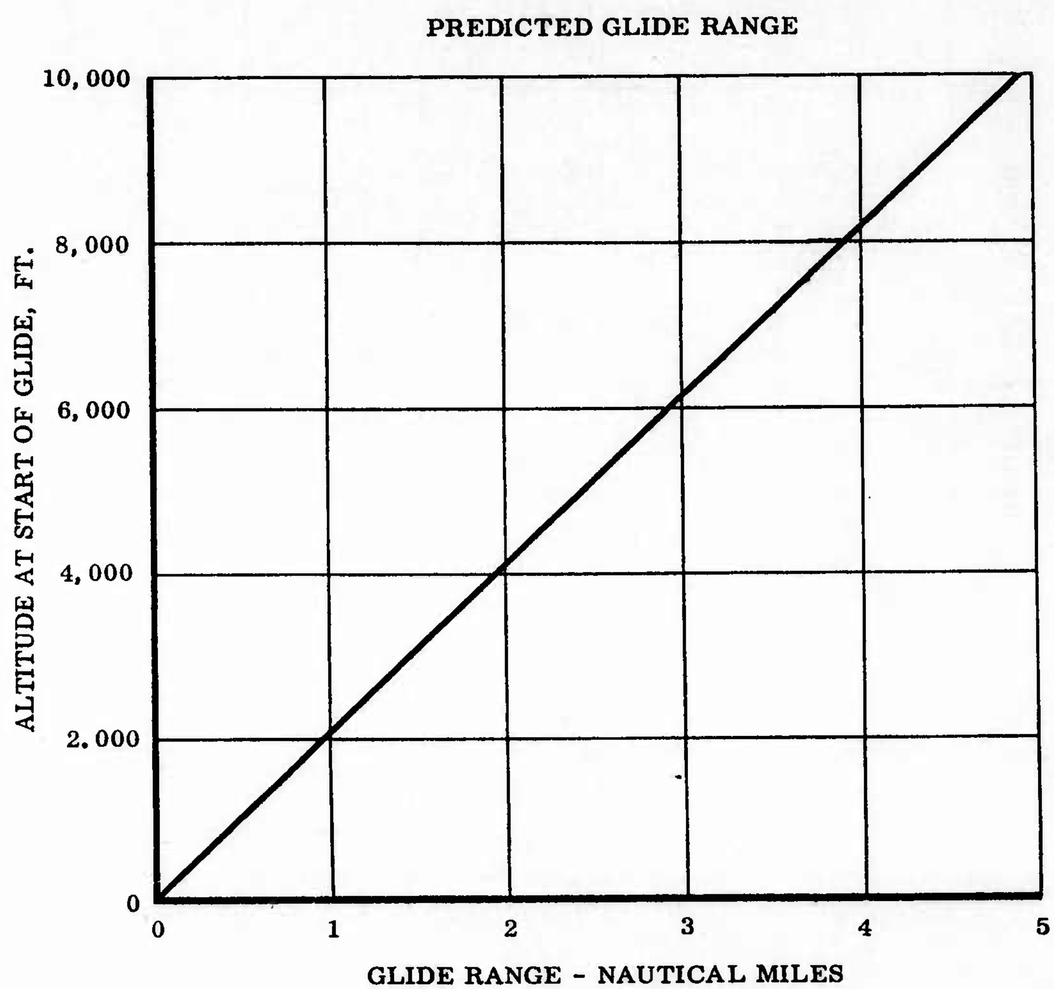


Figure 9 Predicted Glide Range

Since the proposed configuration consists of the wing deployed initially reefed to a state resembling a parachute, deployment shall be made by use of a deployment sleeve and a static line or small extraction chute.

In the analytical treatment of the opening dynamics, the reefed wing (effectively a parachute) was assumed to have the characteristics of a flat, circular parachute. The diameter of 11 feet (D_o) corresponds to the inscribed circle on the wing's flat planform. The associated drag coefficient (C_D) is 0.75. Analysis is presented for opening shock and snatch force, which are the first two peak loading conditions encountered. For this analysis, the following conditions were chosen for the opening shock analysis: Analysis is based on WADC Technical Report 55-265, Section 4.2.1.

Launch Velocity (V_o)	85 knots @ 300 lbs. 95 knots @ 200 lbs.
Launch Altitude (h_o or h_s)	Sea level
Launch Line Length (1_s)	12 feet
Parachute plus Suspension Line Length (1_c)	14.5 feet

The velocity just prior to parachute filling (V_s) can be determined from the following equation:

$$V_s = \frac{V_o}{1 + \dfrac{(C_D S)_B \, \rho \, g \, (t_d) \, (V_o)}{2 \, W_t}}$$

where $(C_D S)_B$ = drag area of cargo container = 5.34 ft.^{2}

ρ = air density = 0.002378 slugs/ft.^{3}

g = gravitational constant = 32.17 ft./sec.^{2}

W_t = suspended weight = 275 lbs. @ 95 kts.
375 lbs. @ 85 kts.

t_d = deployment time = seconds

D_o = parachute diameter = 11 ft.

The velocity V_s is assumed to be equal to V_o. Therefore, the parachute filling time is determined from the equation

$$t_f = \frac{8 \; D_o}{(V_o)^{0.9}}$$

$$t_{f_1} = \frac{(8)\;(11)}{(143.5)^{0.9}} \quad @ \; 300 \text{ lbs.}$$

$$= 1.01 \text{ seconds}$$

$$t_{f_2} = \frac{(8)\;(11)}{(160.5)^{0.9}} \; @ \; 200 \text{ lbs.}$$

$$= 0.91 \text{ seconds}$$

$$\text{Factor A} = \frac{2 \; W_t}{C_{D_o} \; S_o \; V_s \; \rho \; t_f g}$$

$$W_t = 375 \text{ lbs. for G.W.} = 425 \text{ lbs.}$$
$$= 275 \text{ lbs. for G.W.} = 325 \text{ lbs.}$$

$$C_{D_o} = 0.75$$

$$S_o = \frac{D_o^{\;2} \pi}{4} = \frac{(11)^2 \pi}{4} = 95 \text{ ft.}^2$$

$$V_{s_1} = V_{o_1} = 85 \text{ kts} = 143.6 \text{ FPS}$$

$$V_{s_2} = V_{o_2} = 95 \text{ kts} = 160.5 \text{ FPS}$$

$$t_{f_1} = 1.01 \text{ seconds}$$

$$t_{f_2} = 0.91 \text{ seconds}$$

$$A_1 = \frac{(2)\ (375)}{(0.75)\ (95)\ (143.6)\ (2.378 \times 10^{-3})\ (1.01)\ (32.17)}$$

$$= 0.922$$

$$A_2 = \frac{(2)\ (275)}{(0.75)\ (95)\ (160.5)\ (2.378 \times 10^{-3})\ (.91)\ (32.17)}$$

$$= 0.840$$

From Figure 4.2.2, WADC 55-265, the decreasing factor X can be found as

$$X_1 = 0.20$$

$$X_2 = 0.44$$

The opening shock force is

$$F_o = C_{D_o}\ S_o\ q_s\ Xk$$

$k = 1.4$ for a flat circular plate

$$q_{s_1} = 1/2\ \rho\ V_s^2 = (1/2)\ (2.378 \times 10^{-3})\ (143.6)^2$$

$$= 25.26 \text{ lbs/ft}^2$$

$$q_{s_2} = (1/2)\ (2.378 \times 10^{-3})\ (160.5)^2$$

$$= 31.56 \text{ lbs/ft}^2$$

$$F_{o_1} = (0.75)\ (95)\ (25.26)\ (0.20)\ (1.4)$$

$$= \underline{\text{505 lbs. limit}}$$

$$n_{o_1} = \frac{505}{375} = \underline{\underline{\text{1.34 g's limit}}}$$

$$F_{o_2} = (0.75)(95)(31.56)(.44)(1.4)$$

$$= \underline{\underline{1350 \text{ lbs. limit}}}$$

$$n_{o_2} = \frac{1350}{275} = \underline{\underline{4.91 \text{ g's limit}}}$$

Analysis of snatch force is based on WADC Technical Report 55-265, Section 4.1.1. The snatch force for the reefed paraglider is given by

$$P = \sqrt{\frac{W_p}{g} \Delta V^2 \, Z \, \frac{P_{max}}{\epsilon_{max}}}$$

where $\Delta V = V_o^2 \dfrac{t K_b (n-1)}{1 + V_o t K_b (n+1) + V_o^2 n K_b^2 t^2}$

and where $K_b = \dfrac{C_{D_b} \gamma S_b}{2 W_b}$ = drag loading of suspended load, ft^{-1}

C_{D_b} = drag coefficient of suspended load

γ = specific weight of air, lbs. per ft^3

$W_t = W_b$ = weight of suspended load, lb.

S_b = aerodynamic area of suspended load, ft^2

$K_p = \dfrac{C_{D_o} \gamma S_o}{2 W_p}$ for the parachute

where K_p = drag loading of the uninflated parachute, ft^{-1}

$C_{D_o} S_u$ = average drag area of the uninflated parachute, ft^2

W_p = weight of canopy cloth area plus weight of external suspension lines, lb.

Analysis

Let $C_{D_o} S_u = 4\ ft^2$ at full deployment and prior to development of canopy.

$W_p = 49.5$ lbs.

$\gamma = 0.0766\ lbs/ft^3$ = specific weight of air, sea level

$$K_p = \frac{C_{D_o} S_u \gamma}{2 W_p} = \frac{(4)\ (0.0766)}{(2)\ (32.5)}$$

$= 0.00471\ ft^{-1}$ drag loading

$(C_D S)_B = 5.34\ ft^2$

$W_{B_1} = 375$ lbs.

$W_{B_2} = 275$ lbs.

$\gamma = 0.0766\ lbs/ft^2$ = specific weight of air, sea level

$$K_{B_1} = \frac{C_{D_B} S_B \gamma}{2W_B} = \frac{(5.34)\ (0.0766)}{(2)\ (375)} = 0.00054\ ft^{-1} = \text{drag loading}$$

$$K_{B_2} = \frac{C_{D_B} S_B \gamma}{2W_B} = \frac{(5.34)\ (.0766)}{(2)\ \ (275)} = 0.000743\ ft^{-1} = \text{drag loading}$$

$$n_1 = \frac{K_p}{K_{B_1}} = \frac{0.00471}{.00054} = 8.73 = \text{dimensionless ratio}$$

$$n_2 = \frac{K_p}{K_{B_2}} = \frac{0.00471}{0.000743} = 6.33 = \text{dimensionless ratio}$$

d = 14.5 ft.

For: K_p = 0.00471 t_{d_1} = 0.664 seconds @ 85 knots

K_{B_1} = 0.00054

K_p = 0.00471 t_{d_2} = 0.602 seconds @ 95 knots

K_{B_2} = 0.000743

where t_d = time to full extension of suspension line

$$n = \frac{K_p}{K_b}$$

d = distance from the center of gravity of the canopy to the suspension point on the load, ft.

Now $$\Delta V_1 = (143.6)^2 \frac{R_1}{1 + S_1 + T_1}$$

where $R_1 = t_{f_1} K_{b_1} (n - 1) = (1.01)\ (0.00054)\ (5.815\ -1) = 0.00263$

$$S_1 = V_o t_{f_1} k_{b_1} (n + 1) = (143.6)(1.01)(0.00054)(5.815-1) = 0.376$$

$$T_1 = V_o^2 n k_{b_1}^2 t_{f_1}^2 = (143.6)^2 (5.815)(0.00054)^2 (1.01)^2 = 0.0356$$

$$\Delta V_1 = \frac{54.233}{1.4116} = 38.42 \text{ fps}$$

$$\Delta V_2 = (160.5)^2 \frac{R_2}{1 + S_2 + T_2}$$

where $R_2 = t_{f_2} k_{b_2} (n-1) = (0.91)(0.000743)(4.618-1) = .00243$

$$S_2 = V_o t_{f_2} k_{b_2} (n + 1) = (160.5)(0.91)(0.000743)(4.618-1) = 0.388$$

$$T_2 = V_o^2 n k^2_{b_2} t_{f_2}^2 = (160.5)^2 (4.618)(0.000743)^2 (0.91)^2 = 0.0539$$

$$\Delta V_2 = \frac{62.6}{1.442} = 43.41 \text{ fps}$$

t_f substituted for t_d in calculation of ΔV.

$W_p = W_c = 49.5$ lbs.

Z = six lines effective in parachute configuration

P_{max} = 1000 lbs. (breaking strength of suspension lines)

ϵ_{max} = Maximum elongation of suspension line, ft. (approx. 30%)

$$P_1 = \sqrt{\frac{49.5}{32.17} (38.42)^2 (6) \frac{(1000)}{3}}$$

= 2140 lbs. limit

$$P_2 = \sqrt{\frac{49.5}{32.17} (43.41)^2 (6) \frac{(1000)}{3}}$$

$$= 2415 \text{ lbs. limit}$$

$$n_1 = \frac{2140}{375} = 5.7 \text{ g's limit}$$

$$n_2 = \frac{2415}{275} = 8.79 \text{ g's limit}$$

The third peak loading condition which occurs during transition to the wing position from the parachute configuration is not investigated, as flight tests on the Individual Drop Glider demonstrated that this phase of the deployment sequence is not structurally critical. The first two peak loading conditions occur during the deployment sequence. The critical forces which occur are the snatch force and the opening shock force.

Gust Loads

The analysis indicates that the effects of gusts upon the system are relatively low. Because of its extreme flexibility, the paraglider is expected to act as a gust alleviator. In addition, the long Nylon suspension lines will absorb some of the shock of a gust load.

The loads imposed on the paraglider during glide and impact will be quite small. High load maneuvers during glide are not anticipated, and time histories of landing impact indicate a maximum limit load factor of three g's. The glide phase of the descent will consist of a straight glide and/or shallow turns as required for positioning over the intended landing site.

Leading Edge and Keel Load Distribution

Deployment of the wing into the glide configuration results in a momentary wing angle of attack of 90 degrees. The data available from the wing tunnel pressure tests of a model simulating a flexible wing have been analyzed for the loading distribution upon the wing structural members. The following Figure 10 shows the estimated load distribution on the keel and leading edges due to membrane load for two sweepback angles. The load distribution on the leading edges and the keel is practically identical, so each of the curves are valid for all three members. The curves show the loading distribution for the two sweepback angles to be very similar, and both approach a triangular distribution. The variation with sweepback angle, of the center of pressure location, percent wing load on keel, and centroid of airload on the structural members, is shown in Figure 11. These parameters are shown to be essentially constant for the range of sweepback angle shown, at a 90 degree angle of attack. The data also show that the keel supports 50 percent of the wing load, and each leading edge carries 25 percent.

An estimate of the airload distribution on the wing during glide and flare was made by study of the pressure data made available by NASA. Figures 11a and 12 show the load distribution on the wing, heel and leading edges.

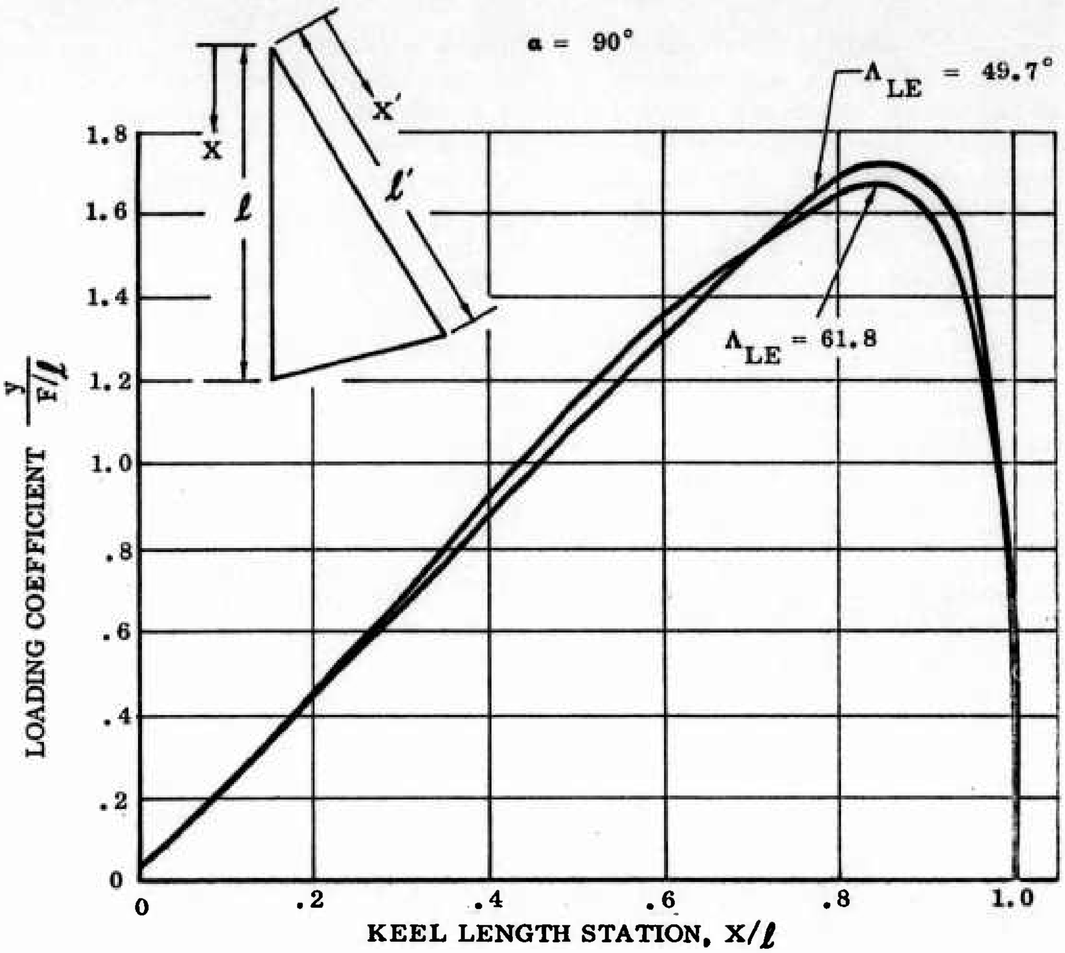


Figure 10 Theoretical Keel and L. E. Membrane Load Distribution

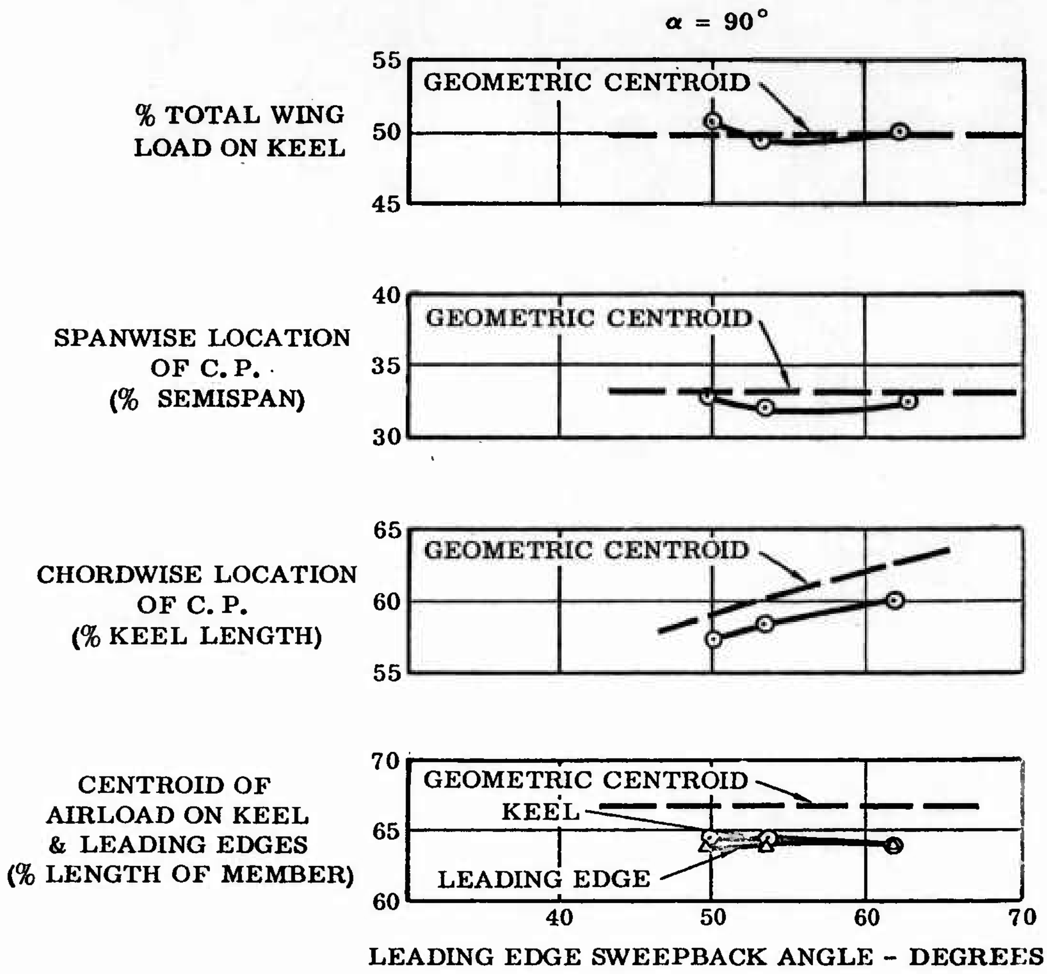


Figure 11 Theoretical Wing Airload Characteristics

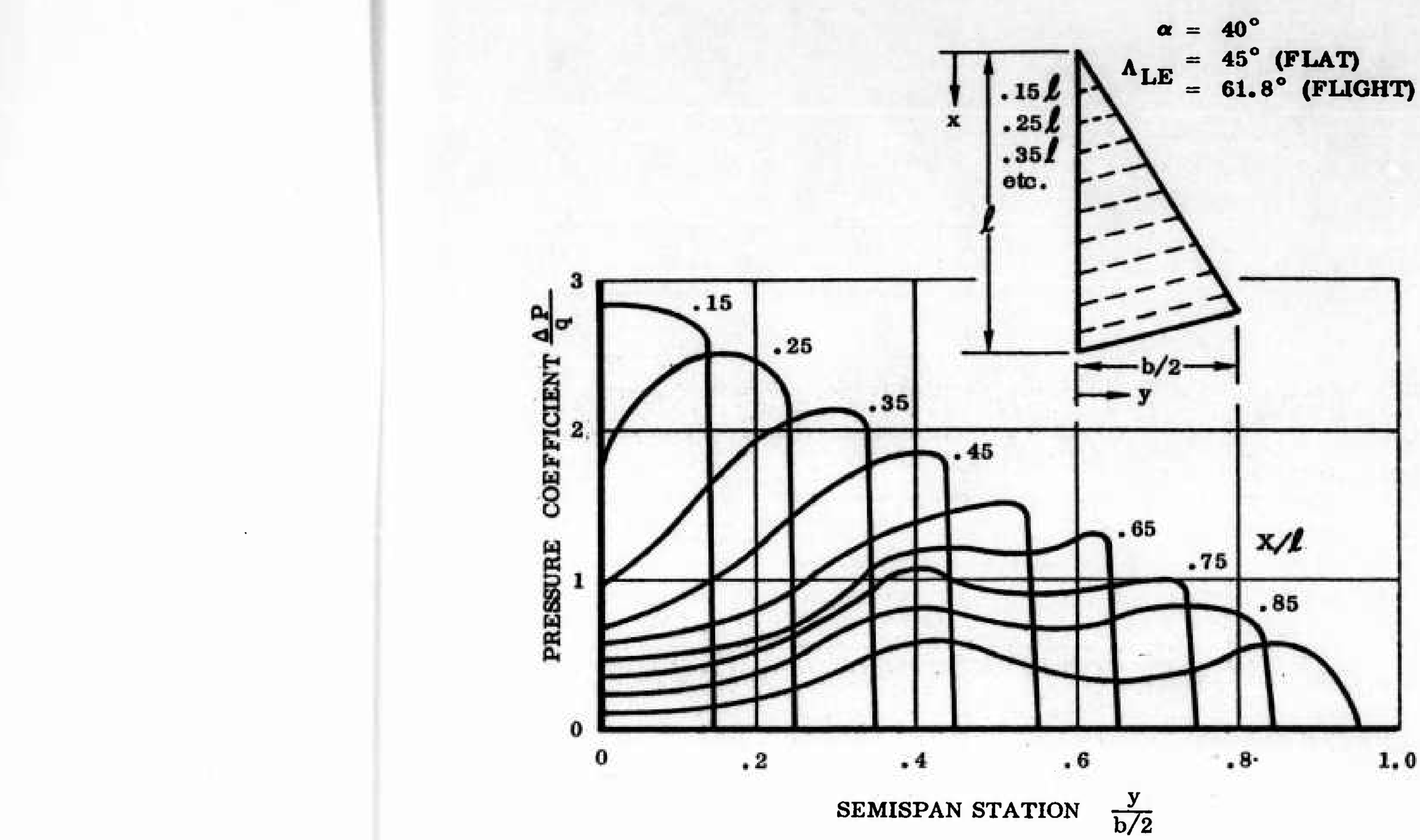


Figure 11a Theoretical Wing Airload Distribution

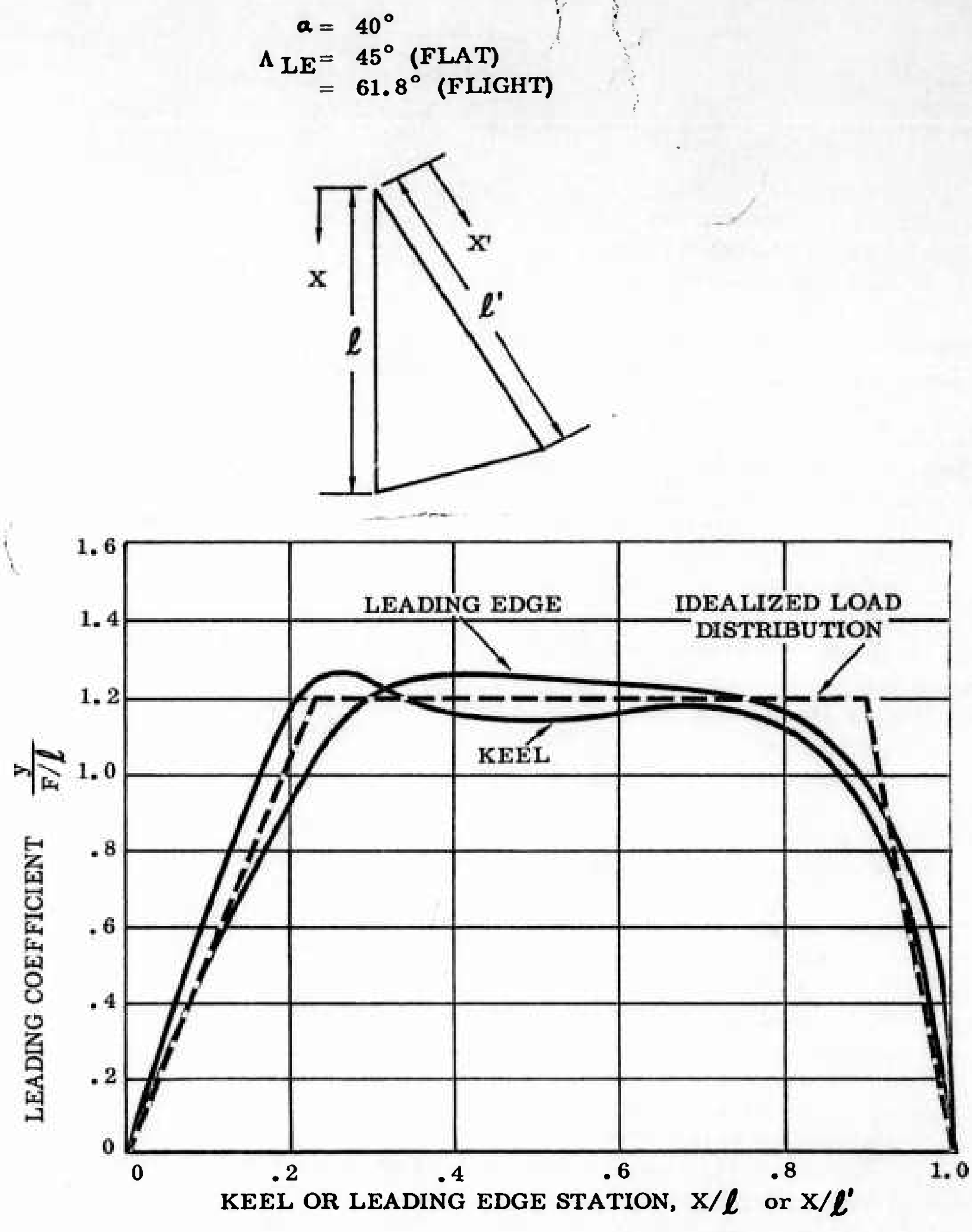


Figure 12 Theoretical Keel and L.E. Membrane Load Distribution

DESIGN

The test vehicle consisted of four major subsystems:

1. Wing
2. Suspension system
3. Flight control system
4. Cargo container

Throughout the test program, modifications were made to the test vehicle. Most of these modifications involved the wing and included such items as packing methods, structural modifications, and flight control response changes.

The basic concept of the system, however, was not changed. The description of the test vehicle which follows refers to the original test vehicle. All changes incorporated during the test program are listed in chronological order in Table 1.

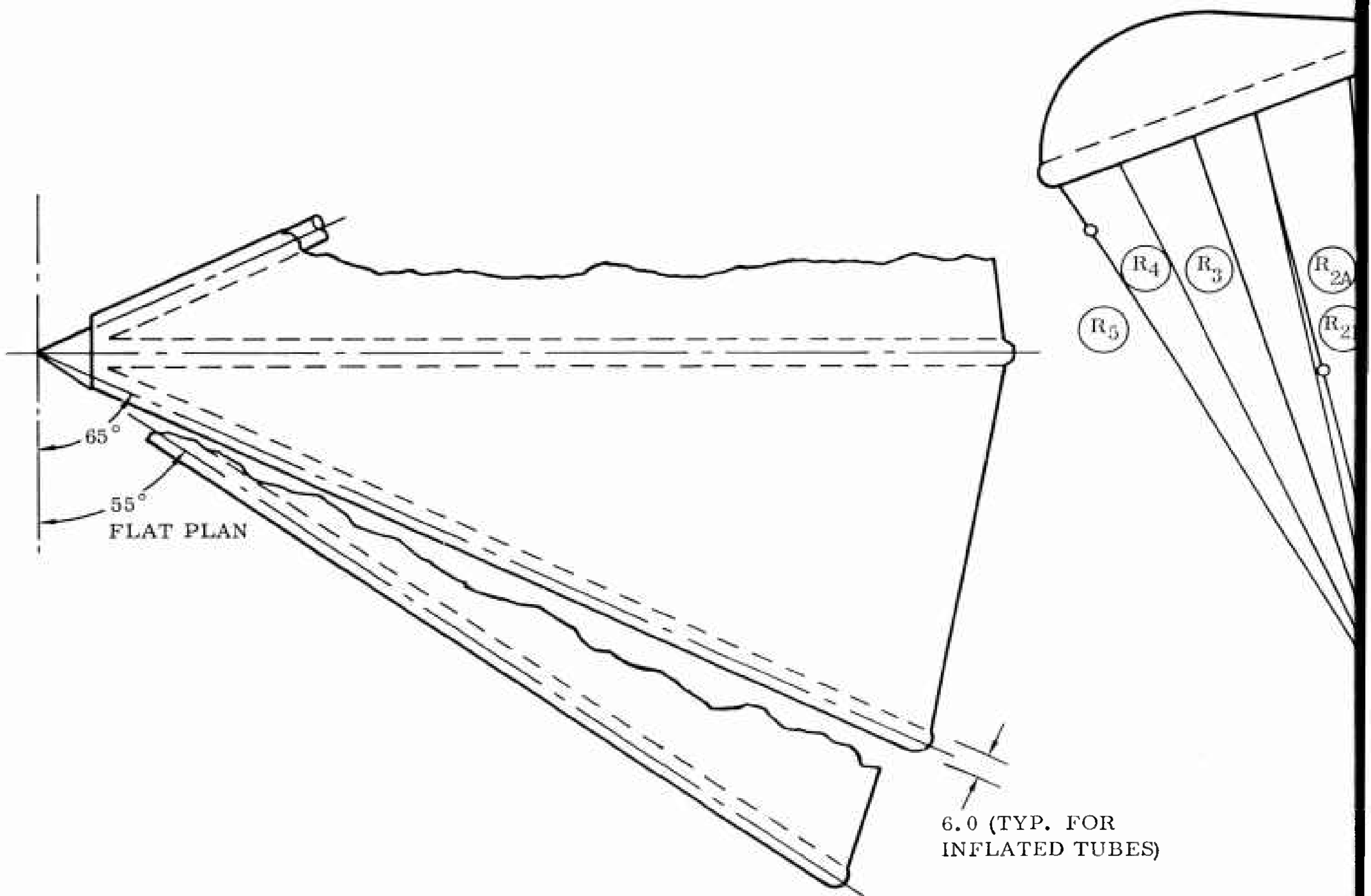
Wing, General

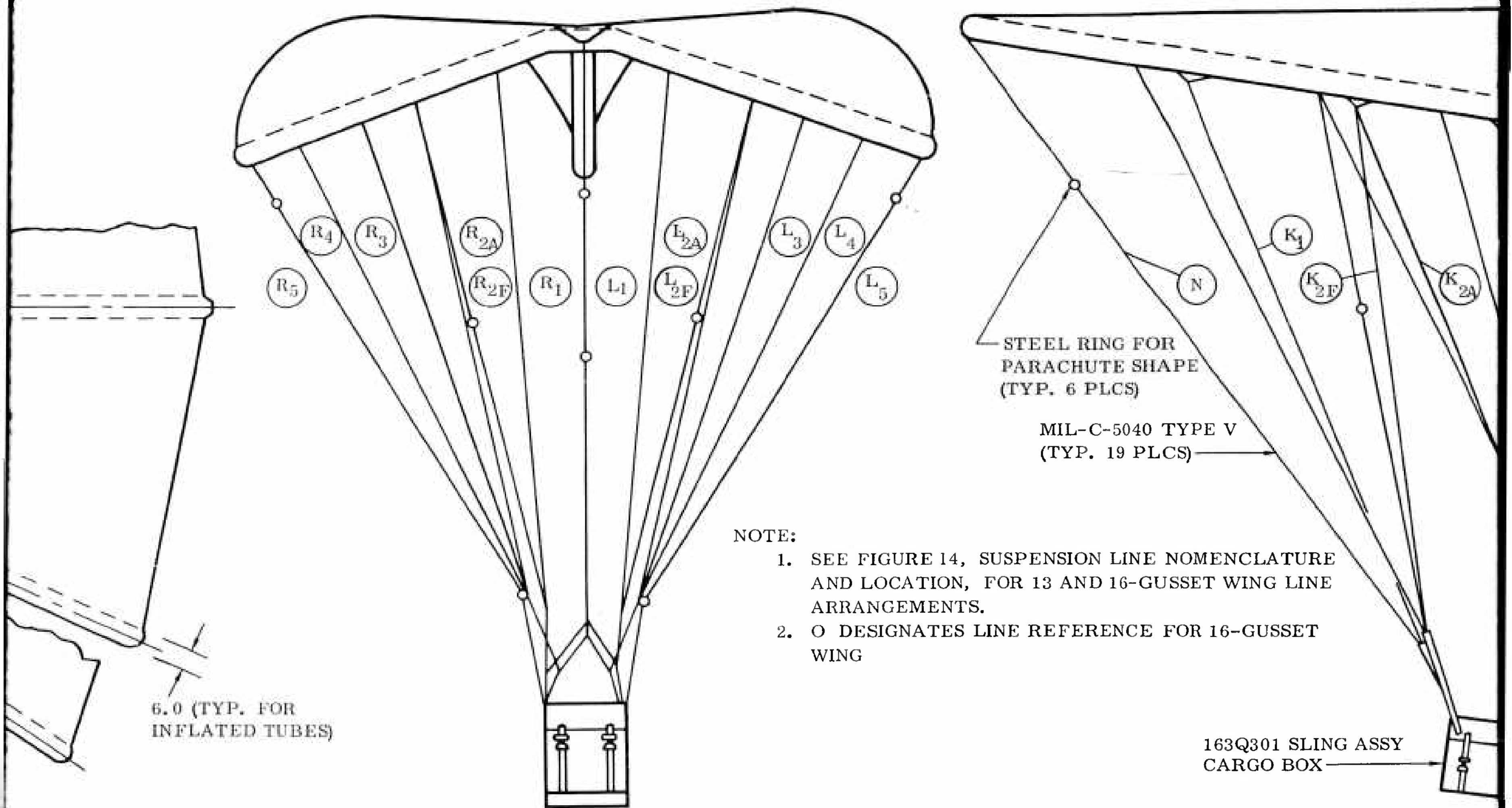
The paraglider wing consists of three inflatable structural members, a flexible membrane, and an air inflation system. The structural members consist of two leading edges and a keel. The two leading edges join at the apex to form a near-triangular wing planform. The keel runs longitudinally aft from the apex along the centerline of the wing, as shown in Figure 13.

The three structural members are bonded together at the apex and form a single inflatable air chamber. Each member is 6 inches in diameter and 22 feet long.

The flexible membrane is continuously attached to the leading edges and keel. The wing has an area of 277.6 square feet in flat planform and a sweep angle of 55 degrees. The membrane and inflatable tubes are made of 3.2-ounce dacron coated on both sides with 4222 polyester coating for an overall weight of 7.95 ounces per square yard.

The original air inflation system consisted of a 125-cubic-inch high-pressure air bottle mounted in the aft end of the keel. A valve, actuated by a reefing cutter, released the air into the keel and leading edges, resulting in a tube pressure of approximately 4 psig. Initially, the air bottle was charged to approximately 4000 psig. In order to alleviate a line pickup problem, a larger capacity air bottle (205 cubic inches) was incorporated midway in the test program.


65°
55°
FLAT PLAN
6.0 (TYP. FOR
INFLATED TUBES)
R4
R3
R5

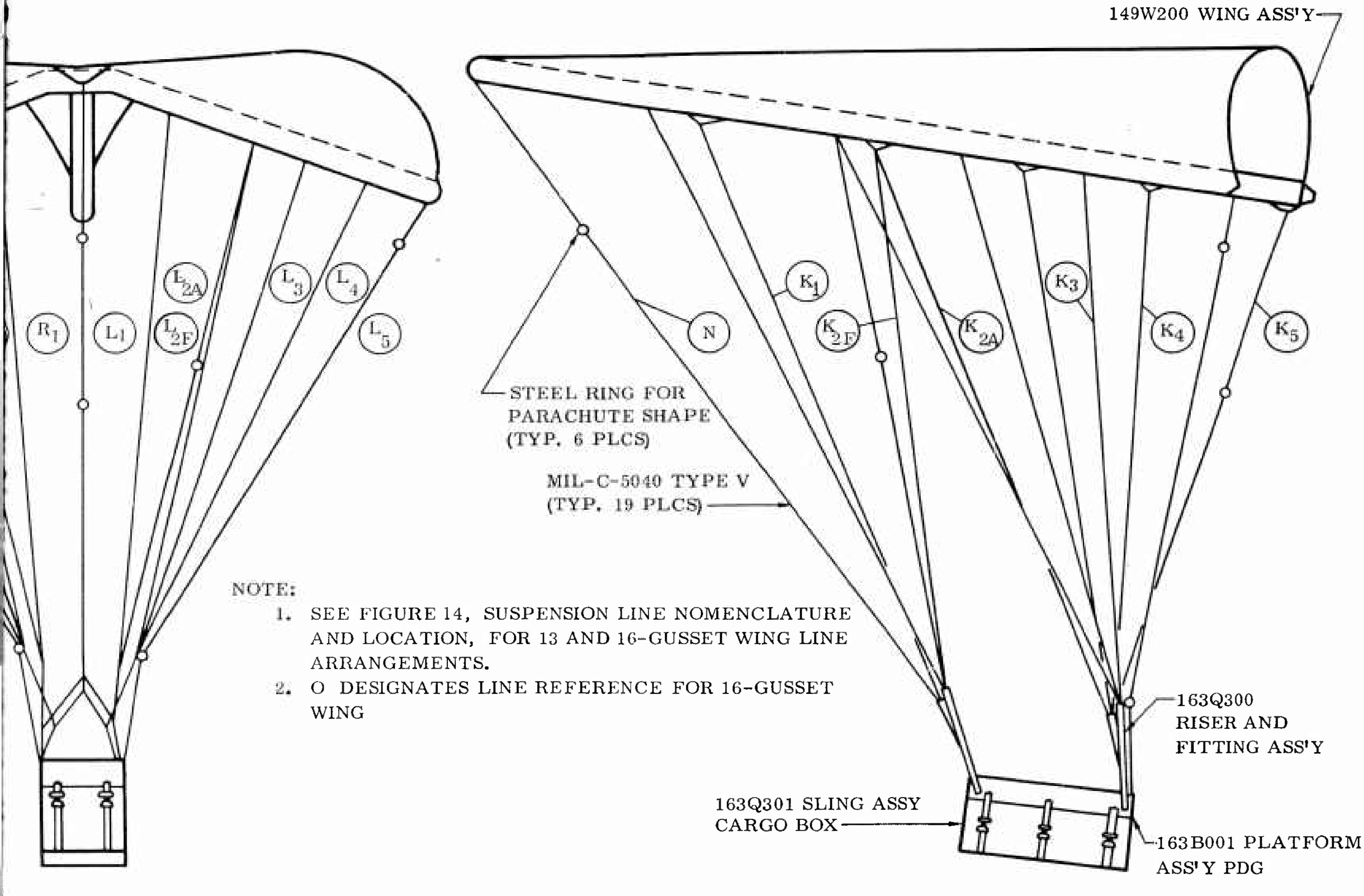


NOTE:

1. SEE FIGURE 14, SUSPENSION LINE NOMENCLATURE AND LOCATION, FOR 13 AND 16-GUSSET WING LINE ARRANGEMENTS.
2. O DESIGNATES LINE REFERENCE FOR 16-GUSSET WING

Figure 13 General Arra

2



NOTE:

1. SEE FIGURE 14, SUSPENSION LINE NOMENCLATURE AND LOCATION, FOR 13 AND 16-GUSSET WING LINE ARRANGEMENTS.
2. O DESIGNATES LINE REFERENCE FOR 16-GUSSET WING

Figure 13 General Arrangement

Thirteen fabric gussets with metal load bars and attachment eyelets were bonded to the leading edge membrane and keel, as illustrated in Figure 13. These gussets were used as attach points for the lines of the suspension system. A 16-gusset wing was later introduced into the test program in order to obtain a better load distribution at the aft section of the structural members. The annotations contained in Table 4 represent the suspension line nomenclature.

Wing Numbers 101 and 102

These two wings were 13-point attachment wings (as shown in Figure 14) fabricated with a 3.2-ounce-per-square-yard dacron base cloth coated on both sides with a 4222 polyester coating for an overall material weight of 7.95 ounces per square yard.

The aft leading edge suspension lines were attached to a fabric gusset with an integral load bar and eyelet which distributed loads directly into the membrane. The aft keel suspension line attachment point distributed loads directly through a double fabric gusset with integral load bars and eyelets into the membrane of the wing.

Wing Numbers 103 through 112

These 10 wings were 16-point attachment wings (as shown in Figure 14) fabricated with 3.2-ounce dacron base cloth coated on both sides with a 4222 polyester coating for an overall weight of 7.95 ounces per square yard.

Sixteen gusset wings were utilized exclusively on this program after flight test operation (FTO) 41, in order to distribute internal loading within the tube members more evenly in the area of higher wing loading, thereby retaining the wing's shape and gliding capability in the event of tube pressurization loss.

At the same time, a 205-cubic-inch pressurized air bottle, which yielded 9 psig internal tube pressure when the bottle was pressurized to 3400 psig, was incorporated into the program. This change was initiated to assist the wing when transitioning from the parachute mode into the glider mode by providing a more positive action and helping to alleviate any line pickup tendencies .

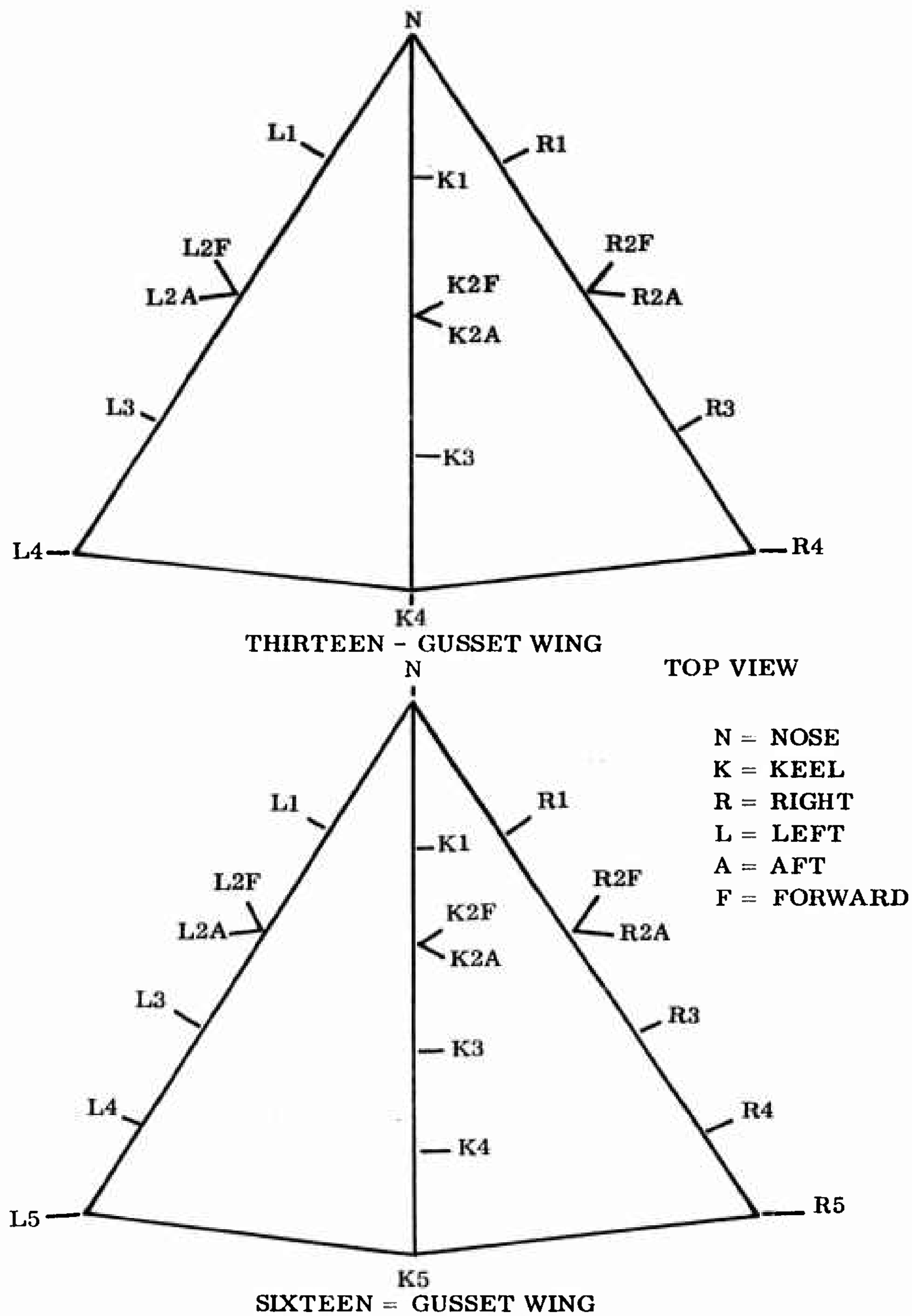


Figure 14 Suspension Line Nomenclature and Location

Suspension System

The 13-gusset wing consisted of 16 suspension lines, while the 16-gusset wing had 19 suspension lines. In both cases, the lines were attached to two sets of riser straps. The suspension lines were MIL-C-5040 Type VII 1000-pound test nylon; the riser straps were MIL-W-4088 Type VII standard nylon parachute webbing. All suspension lines were secured to the gussets on the wing and to the riser strap attachments by standard parachute knots. The riser strap assembly was fitted with quick-disconnect latches for rapid separation of payload from the paraglider.

The glider line nomenclature, as presented in Table 4, has three letters to designate the tube from which the glider line extends: L (left), K (keel), and R (right). Those glider lines, which attach to a common gusset, differentiate which line is forward (f) and aft (a).

Steel rings in six of the glider lines (Nose, L2f, R2f, L4, K4, and R4) for the 13-gusset wings (and Nose, L2f, R2f, L5, K5, and R5 for 16-gusset wings) were snubbed down to lengths presented in Tables 5 and 6 for the various parachute modes investigated. After a delay of 4 to 6 seconds, the actuated reefing cutter fired, releasing the snubbed lines and permitting the flexible wing to commence a transition to the wing configuration. The methods by which these rings were restrained were:

1. Riser Reefing Cutter Latch. Latches attached to the center webbing of the risers took up the opening shock loads from the parachute rings. The latch was held closed by nylon line secured at the ends of the latch. The line was cut at 4 (or 6) seconds by a pyrotechnic reefing cutter and the rings were released, initiating the transition to the glider mode. Loop variations of 1000-, 2000-, and 3000-pound test line were evaluated as well as single latch and fore-and-aft (double) latch configurations. The single latch did not provide any resistance to twisting between the parachute and the payload; the double latch arrangement would not release both latches simultaneously.

2. Control Box Mechanical Latch. Two latches were mounted in the control box, one forward and one aft. Upon activation of the 6-second cutter, a line inside the control box holding the mechanical latches closed under high tension was cut and both spring loaded

latches opened simultaneously. The fore-and-aft arrangement prevented any significant twisting of the parachute lines.

Control System - Electrical and Electronic

A remote control system was used to control the glider during descent. The ground control station consisted of a transmitter-coder, a 28-volt battery power supply, and an antenna. The airborne system consisted of a six-channel receiver/decoder, power supply, and an actuator motor system which operated the para-glider control lines. Only three of the six channels were utilized.

The forward compartment of the airborne control box Figure 15, contains:

1. SK401186 radio control receiver
2. 28-vdc battery power supply and box
3. Antenna network and fittings
4. Battery charging connection
5. Associated wiring and cable assemblies

The aft compartment contains:

1. Rotary actuator motor assembly
2. Motor cooling fan
3. 12-vdc battery
4. Two diodes
5. Relay box
6. Four limit switches
7. Two fairlead assemblies
8. Battery charging connection
9. Master control switch
10. Two terminal blocks
11. Servo test switch
12. Micro-switch actuator assembly
13. Associated wiring

The airborne control receiver is solid state and powered by batteries with a 1-hour minimum life (equal to two maximum range recoveries). The size of the receiver unit is approximately 5 x 5 x 3 inches. The receiver consists of two identical superheterodyne receivers with a common local oscillator, summed automatic gain control, and a control logic system.

During the homing operation, the 133-megacycle control signal is amplitude modulated by a 977-cps audio signal. The modulated 133-megacycle signal received at each receiving antenna, Figure 16, is amplified at radio frequency, converted to an intermediate frequency, amplified, and demodulated to audio frequency. The 977-cps audio frequency is fed to the logic relays through selective band-pass filters, energizing homing relay K2. The processed signal from each VHF amplifier is also fed through the gating network to the differential detectors. Audio voltage from the filter-driven amplifier passes through the closed contacts of the energized home relay K2 to trigger the post-detection gate and to actuate either the "left" home relay K4 or the "right" home relay K5 in response to the unbalance of the input signals. Control functions of the Precision Drop Glider do not require use of the 1385-, 1838-, and 2500-cps filters and associated relays.

The remote control transmitter is completely solid state and powered by a separate battery pack. The battery has a minimum 10-hour life, equal to 20 maximum range recoveries, and is rechargeable. The transmitter, Figure 17 consists of a crystal-controlled oscillator, tone generators, and the required frequency multipliers and power amplifier. The radiated power is approximately one-half watt at a frequency of 133 megacycles. The transmitter is amplitude modulated by three tone generators. The 977-cps tone generator provides a tone frequency for homing. The 312-cps or 525-cps tone generators provide tone frequencies for left and right turn commands, respectively. Battery power is used only during homing or command signals; no standby power or warming-up is required. The homing signal can be overridden at any time by operating the command switches at the transmitter. Return to homing control is immediate and automatic in the absence of command signals. The transmitter antenna is one-quarter wave length vertical ground plane Figure 18.

The automatic control mode is similar to a beam rider technique. It can be used for all-weather or night operation. The remote ground station operator, after establishing voice radio communication with the delivery aircraft, and when informed of the time of drop, positions the transmitter power switch and homing switch to ON. The glider will then ride the beam from the drop point to the transmitter at the landing site; when over the transmitter, the glider will spiral glide to a touchdown.

Homing and guidance are achieved by the use of three audio tone generators which produce modulated signal frequencies for use in initiating manual left or right

turns or homing. Control logic is such that, when in the home mode the signal strength in one channel exceeds that in the other channel, the glider will commence turning toward the signal source (transmitter). When the signal strengths become equal (with a pre-set difference), the glider continues on its new heading until a new unbalanced signal condition is received.

The manual control operator, after establishing voice radio communications with the delivery aircraft, and when informed of the time of drop, positions the transmitter Power Switch to ON and , when the drop is made by the delivery aircraft, overrides the homing switch and controls the glider direction on the glide path by manual "right" or "left" commands to bring the glider to the selected landing spot. Angle of descent is a function of the design and rigging of the flex-wing and is not subject to control by the remote control operator. The procedure would therefore be to bring the glider over the landing spot with excess altitude and make the landing after a spiral descent. Using a continuous "right" or "left" command, the flexible wing will circle approximately 200 to 400 feet in diameter, and descend about 200 to 300 feet during each 360-degree turn.

Lateral and longitudinal control was originally attained by shifting the suspended weight (payload center of gravity) with respect to the wing center of pressure. A turn was normally accomplished by shortening one and lengthening the other of the two rear riser straps, Figure 19. During the flight test program, c. g. shift control was changed to obtain more definite lateral control response. This change was accomplished by removing the leading edge glider line, R5 and L5, from the aft risers, permanently attaching the aft risers to the control box in a manner similar to the forward risers, and then lengthening these two lines to extend into the control box. These two glider lines were then shortened or extended to obtain directional control. By holding the remaining leading edge glider lines constant, displacement of the two aft lines created an "aileron" effect in the wing rather than the c. g. shift obtained from the aft riser displacement method. This method remained in effect throughout the remainder of the feasibility test program.

The line used for control was terminated at a point on the screw jack in the aft compartment of the control box. The servomotor system used to operate the system is shown in Figures 20 and 21. Traveler motion was designed for ±8 inches of motion from the neutral position. No flare control was used or needed for landing.

Three basic configurations were used during the flight test program for mechanical conversion of the radio control link output signals to produce lateral-directional control response.

1. Direct aft riser strap attachment to the traveler of the linear actuator shaft.

2. Direct aft glider control line, L5 and R5, attachment to the traveler in conjunction with a pulley system. Aft risers were attached to the control box.

3. Direct aft glider control line, L5 and R5, rotary wound on the actuator shaft instead of the traveler. Aft risers were attached to the control box.

The aft riser strap method was used until FTO 33. See Figure 19 for configuration arrangement. Upon receipt of a command signal from the flight control system, the screw jack would displace the traveler to the left or right and the direct linkage would produce a 1:1 motion of the aft riser straps. This mechanism was utilized as the method of control associated with the philosophy of payload center-of-gravity shift with respect to the wing center of pressure. The turn was accomplished by shortening one and lengthening the other of the two aft riser straps an equal amount.

Starting with FTO 34, the aft riser straps were removed from the linear actuator traveler and were attached to the control box in the same manner as the forward riser straps. The aft glider lines, L5 and R5, were routed into the control box through a pulley system and around the traveler and dead-ended at the side walls of the control box. The external dimensions of the L5 and R5 glider (control) lines remained the same over the distance from the entry to the control box to the No. 5 gusset. Internal dimensions were increased to accomodate the added travel of the modified system. These two control lines were shortened or extended due to traveler displacement to obtain directional control. By holding the remaining leading-edge glider lines constant, the displacement of the aft glider lines created an aileron effect in the wing rather than the c. g. shift resulting from the original riser displacement.

This system was referred to as the "double control" system because of the internal routing of the control lines and the resulting mechanical advantage of "two" achieved through the use of the pulleys in the system.

As an alternate arrangement, a "triple-control" system was evaluated wherein the addition of another line length and pulley provided a mechanical advantage of "three" in an attempt to increase the controllability of the wing.

The rotary-wound system, shown in Figure 22, was incorporated into the test program at FTO 118 and continued until the duration of the program. In this configuration, the aft glider lines, L5 and R5, were routed into the control box and wound around the shaft of the linear actuator, where they were then secured to the shaft by clamps.

The resultant throw of control glider lines L5 and R5 was limited to a maximum of ±7-1/2 inches from the neutral position in the homing mode and ±9 inches from the neutral position in the manual mode by limit switches. The advantage of the rotary-wound control line displacement method was the attainment of an increased response rate which was more compatible with the receiver control system.

Cargo Container

Cargo containers of two different sizes were used during the course of the test program. Normally, the container size was 16 cubic feet, 4 feet x 2 feet x 2 feet, except for those drops delivered from the U-6A (L-20). The small exit door required that the height of the box be lowered from 2 feet to 16 inches. Change of payload size produced no noticeable change in flight performance of the PDG vehicle. In the latter part of the test program, in an effort to eliminate center-of-gravity (c.g.) shift as a possible variable in the flight control problem, the lead ballast was secured to a plywood pallet.

The cargo container was a fabricated cardboard container of double wall construction with full overlap bottom and an 8-inch overlap top. The outside container material was V3C waterproof, 400 pounds per square foot; the inner line or sleeve was triple-wall, non-waterproof, 600-pound-per-square-foot cardboard.

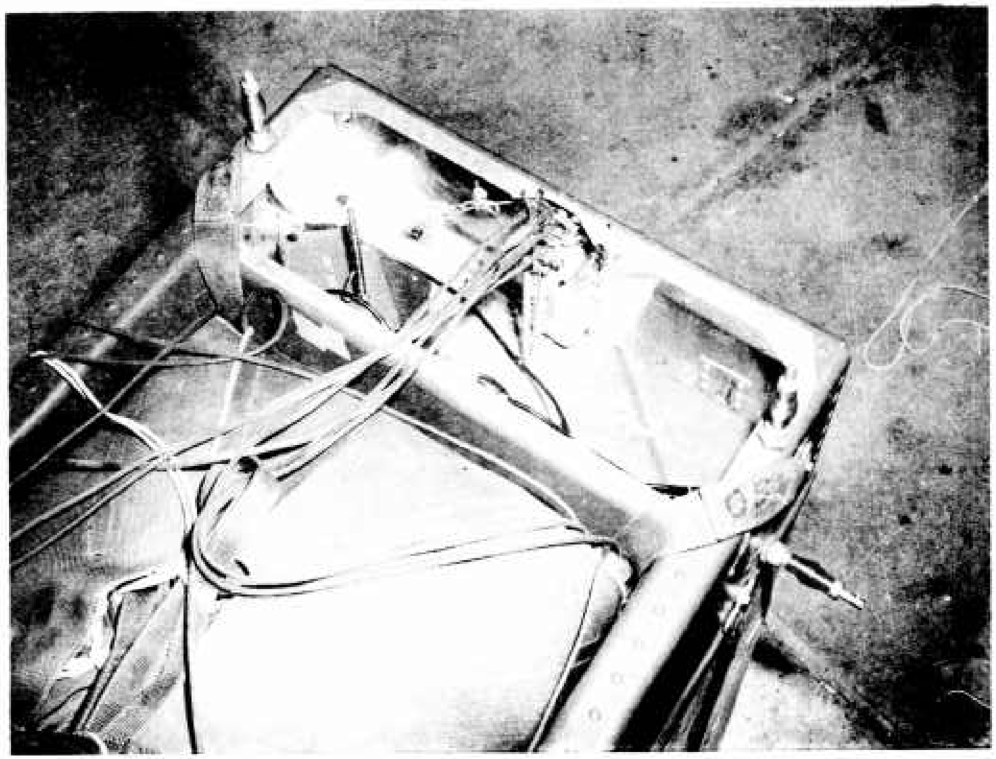


Figure 15 Paraglider Control Box, Forward Section

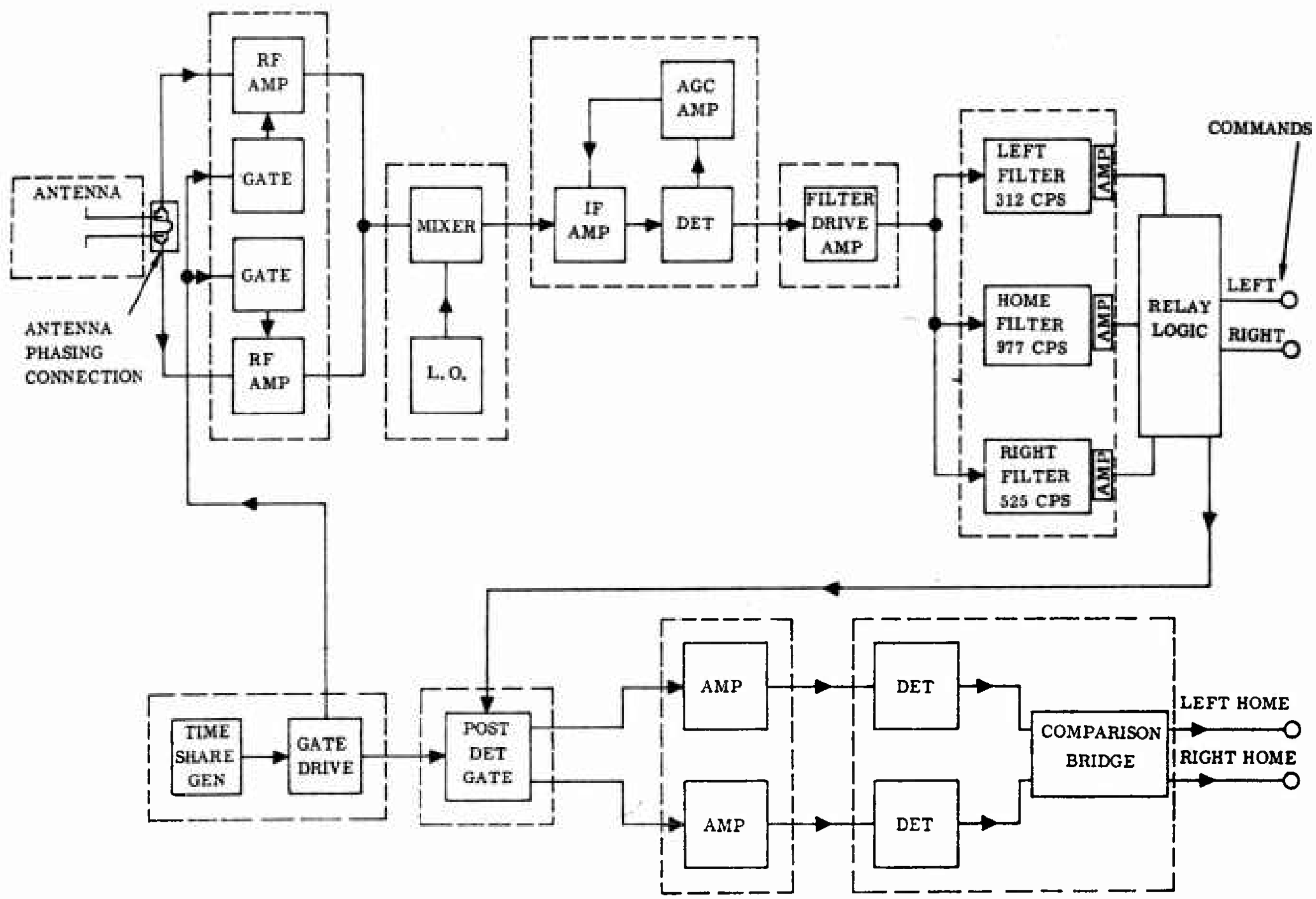


Figure 16 Control Receiver, Block Diagram

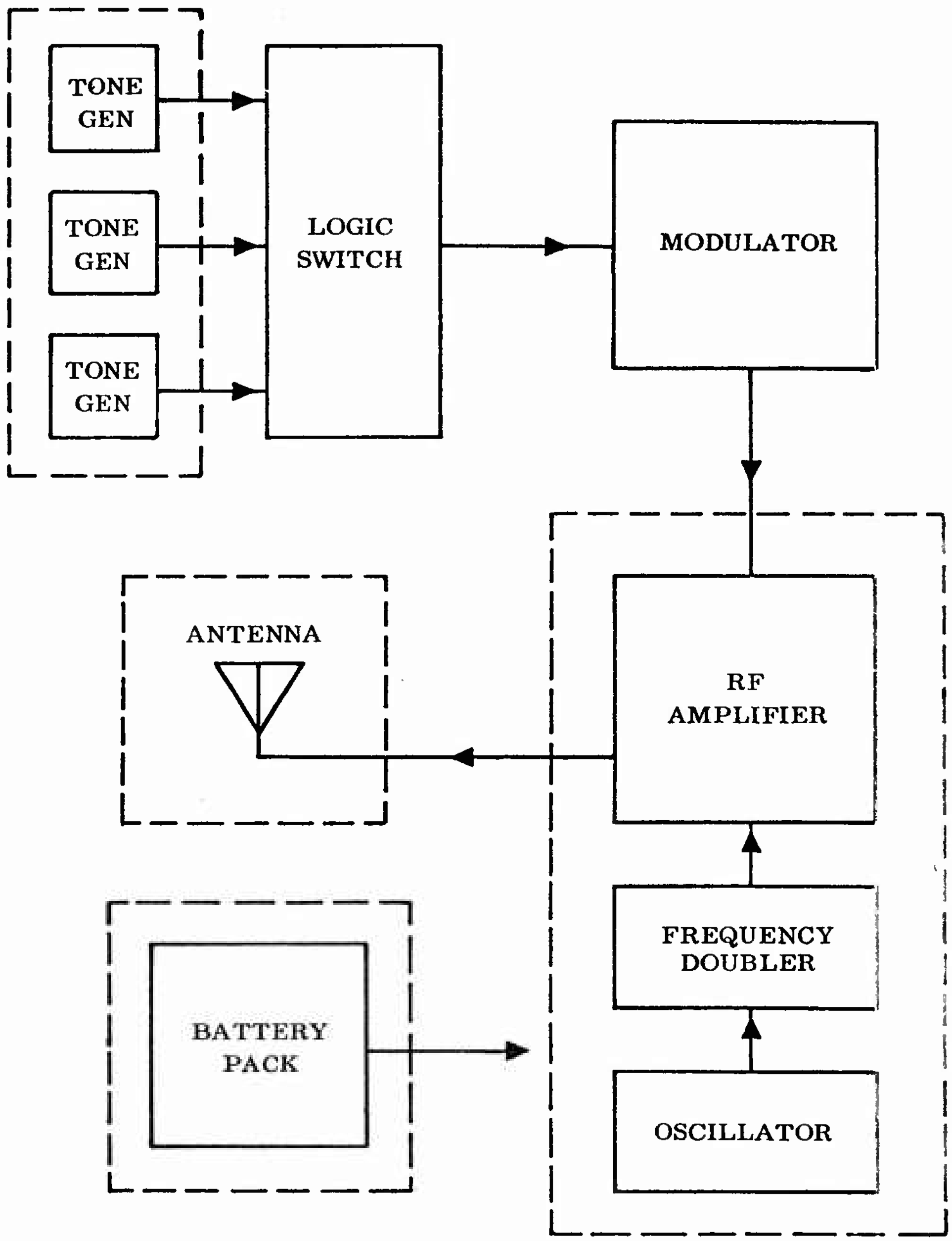


Figure 17 Control Transmitter, Block Diagram

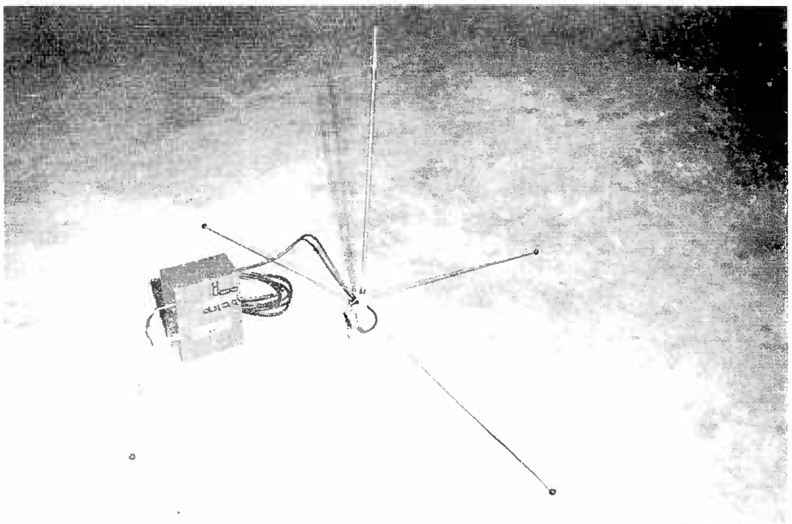


Figure 18 Ground Control Station Transmitter and Antenna

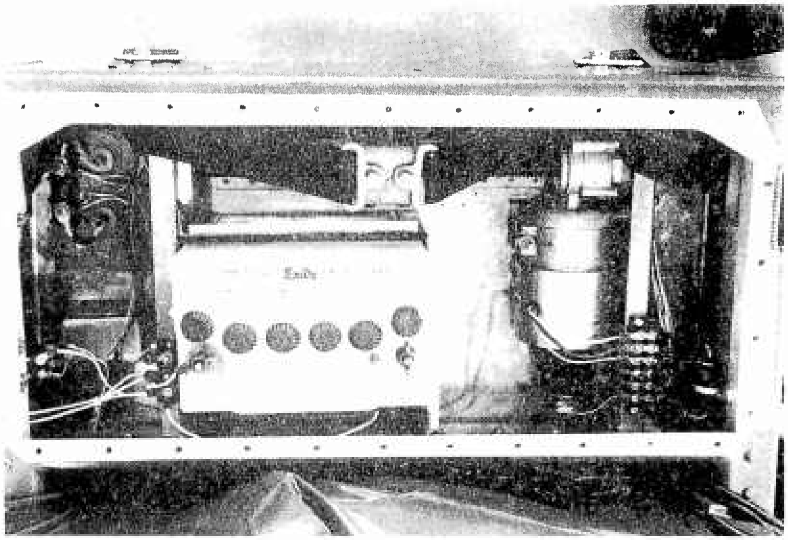


Figure 19 Aft Control Box Section, Riser Control

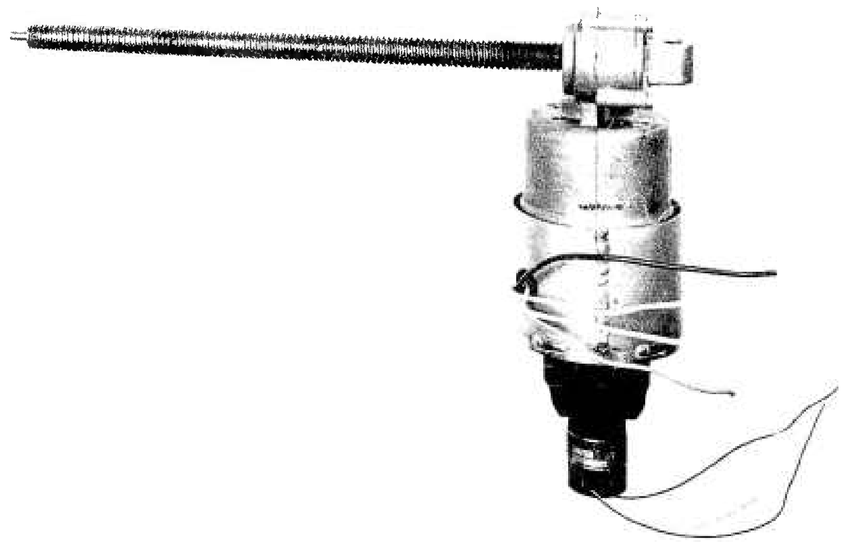


Figure 20 Paraglider Control Servo Motor

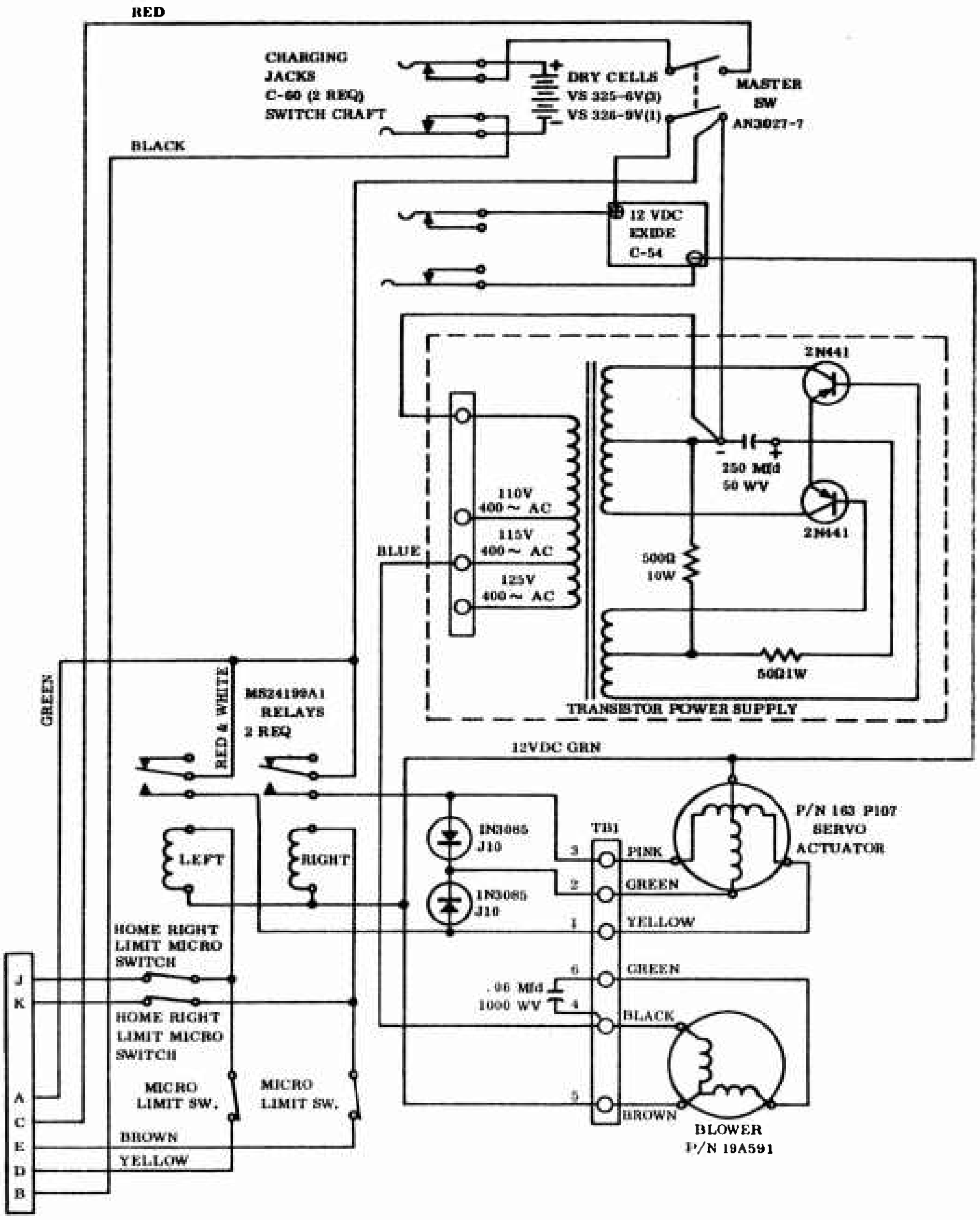


Figure 21 Paraglider Control Box, Schematic Diagram

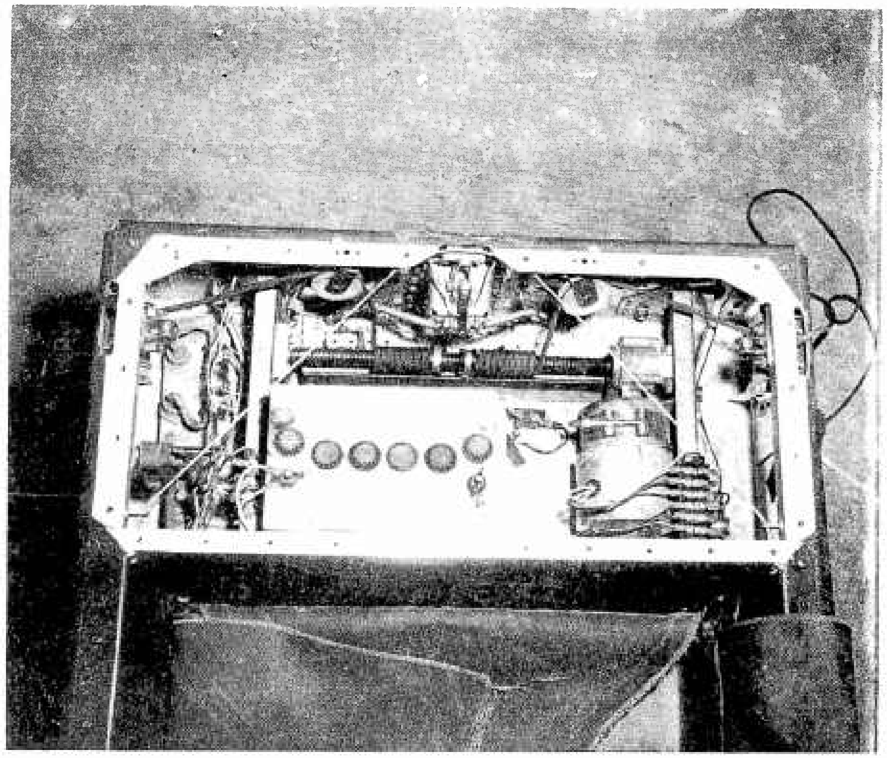


Figure 22 Aft Control Box Section, Rotary Wound Control

STRESS ANALYSIS

Wing Analysis - Parachute Configuration

Limit opening snatch load factor = 8.79 g's (G.W. = 325 lbs.)
= 5.7 g's (G.W. = 425 lbs.)
Reference: Page 32 of this report

Suspension Line Analysis

$$\text{Design Load} = \frac{F_o jc}{Zuoek}$$

F_{o_1} = 5.7 (375) = 2140 lbs. limit

F_{o_2} = 8.79 (275) = 2415 lbs. limit

F_o = maximum opening force

j = safety factor = 1.5 for aerial delivery of cargo

c = factor related to suspension line convergence angle. For suspension line lengths approximately equal to parachute diameter, c = 1.055

Z = number of suspension lines

u = factor involving the strength loss at the connection of suspension line and drag producing surface or riser respectively = 0.80

o = factor related to strength loss in material from water and water vapor absorption.

e = factor related to strength loss by abrasion = 1.00

k = factor related to strength loss by fatigue = .95

$$\frac{j}{uoek} = \text{design factor} = 2.08 \quad \text{Note: } j = 1.50$$

$$(\text{Design Load})_1 = \frac{(2140)\ (1.055)\ (2.08)}{6} = 782 \text{ lbs/line ult.}$$

$$(\text{Design Load})_2 = \frac{(2415)\ (1.055)\ (2.08)}{6} = 885 \text{ lbs/line ult.}$$

Nylon cord, coreless Mil-C-7515 B
Breaking strength = 1000 lbs.

$$\text{M.S.} = \frac{1000}{885} - 1 = \underline{\underline{0.13}}$$

Membrane Analysis (Canopy)

The snatch force is F_{o_2} = 2415 lbs. limit.

Therefore, the instantaneous canopy loading is

$$\frac{F_o}{C_{D_o} S_o} = \frac{2415}{71.25} = 33.9 \text{ lbs/ft}^2$$

$$= 0.235 \text{ psi (Limit)}$$

The maximum radius of the canopy is assumed to be equal to the distance from the top of the canopy to the suspension point. This distance is equal to approximately 210 inches.

The membrane hoop load = N_h = pR

where $\quad p \quad$ = canopy pressure in psi

$$N_h = 0.235 \times 210$$

$$= 49.3 \text{ lbs/in. limit}$$

$$= 49.3 \times 1.5 = 74.0 \text{ lb./in. ult.}$$

The membrane material is a polyester-coated dacron cloth. The cloth weighs 5 oz./yd.^{2} and is 0.006 inch thick. It has a strength of 100 lbs./inch.

$$M.S. = \frac{100}{74} - 1 = \underline{\underline{0.35}}$$

Wing Analysis - Keel and Leading Edges

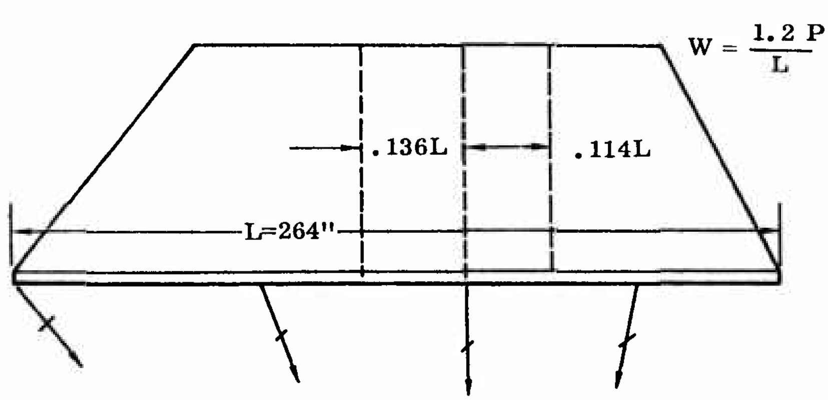
The keel and leading edges of the wing are inflatable tubes fabricated from the same material as the wing membrane. The tubes are 6 inches in diameter unpressurized. The keel and leading edges are similar in design. However, the keel is more highly loaded and will dictate the strength requirements.

The air-load distribution given in the structural criteria and loads section and represented in Figure 12 is utilized for determining the strength requirements. The distribution is based on the latest available wind tunnel data. The actual distribution has been idealized for ease of analysis.

The inflated tubes are assumed to be hinged midway between the suspension lines. These segments are free-bodies as simply supported beams. This assumption is made for ease of calculation. A previous analysis of the beam on elastic supports shows the error to be insignificant.

The resultant load on the keel = p = 0.43N where N = normal force on wing.

N = 1.06W (Resolution of lift and drag forces on wing)
W = 300 lbs.
P = 0.43 (1.06) W
= 0.456W
= 122 lbs.



The maximum moment is given by

$$M_{max} = \frac{W X^2}{2} = \frac{1.2p}{2L}(0.136L)^2$$

$$= 357 \text{ in-lb } (1 \text{ g})$$

$$= 357(2) = 714 \text{ in-lb } (2 \text{ g Limit})$$

The diameter of the keel is 6 inches unpressurized. Tests conducted at Ryan have indicated that inflatable tubes fabricated from dacron coated with polyester increase in diameter by 7 percent when loaded to the yield strength of the material. Therefore, a 6-inch-diameter tube will work at a diameter of 6+ (.07x6) = 6.42 inches. Based on accumulated test data taken from flight tests of inflatable wings, the inflatable tubes are designed to theoretical collapse at limit load.

$M = 714$ in-lbs. (Design bending moment)

The bending stress is given by

$$f_b = \frac{Mc}{I}$$

where $C = 0.698\ R$ (includes effective adjacent material)

and $I = 4.178\ R^3\ t$ (Keel section)

$$F_b = \frac{M(.698R)}{4.713R^3 t} = \frac{M(.698)}{4.713R^2 t}$$

The longitudinal membrane stress is given by

$$\sigma_\ell = \frac{p\ R}{2t}$$

To design for collapse at ultimate load, the bending compression stress is equated to twice the longitudinal membrane stress.

$$\frac{0.148\ M}{R^2 t} = 2\frac{p\ R}{2t}$$

$$p = 0.148 \frac{M}{R^3} \quad \text{(Internal pressure required)}$$

$$= \frac{1071\ (0.148)}{(3.21)^3} = 4.8 \text{ psig req'd}$$

This pressure is somewhat conservative, in that the computed bending moment is conservative. If the relief of moment due to some degree of distribution of load by the cable gussets is taken into account, a slightly lower required pressure would result.

The internal pressure of 4.8 psi induces a hoop stress of $\frac{pR}{t}$ or a hoop lead of pR.

$$N = pR = (4.8)\ (3.21) = 15.41 \text{ lbs./in}$$

Keel Gusset Analysis — Not Critical

The critical load on the forward and aft keel suspension line attachments is derived from the parachute deployment condition. This force, as calculated on page 57 is

$$F_o = 885 \text{ lbs. ultimate design load.}$$

The intermediate keel gussets are loaded during the glide and landing phase only. This load is calculated from the basic assumptions made on page . The critical load is given by

$$F = (0.136L + 0.114L)\left(\frac{1.2P}{L}\right)$$

$$= 36.6 \text{ lbs. (1g)}$$

$$= 73.2 \text{ lbs. limit}$$

$$= 109.8 \text{ lbs. ultimate.}$$

Nose Gussets:

$$F_o = 885 \text{ lbs. ultimate.}$$

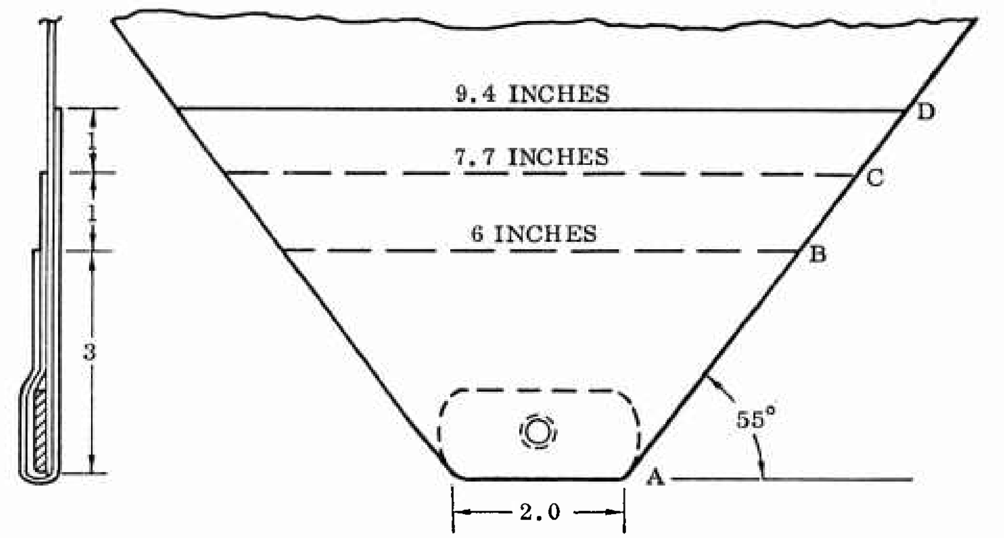
This load transmitted to or from the wing structure by two gussets. The gussets make an angle of approximately 30° to the line load path. Therefore, the resolved load per gusset is given by

$$F_g = \frac{F_o}{2 \cos 30°} = \frac{885}{2 \cos 30°}$$

$$= 511 \text{ lbs. per gusset.}$$

Although the load bar is glued to the gusset, it is conservatively assumed that the total load is transmitted by the load bar bearing on the fabric.

Total load bar force = 511 lbs.
Load bar length = 2 in.
W = 511/2 = 255.5 lbs./in. at Point A



Net tension at Point A

Load = 255.5 lbs./in.

Allowable = (100)* (4)** = 400 lbs./in.

$$M.S. = \frac{400}{255.5} - 1 = \underline{\underline{0.564}}$$

Net tension at Point B

$$Load = \frac{511}{6} = 85 \text{ lbs./in.}$$

Allowable = (100) (3) = 300 lbs. in.

$$M.S. = \frac{300}{85} - 1 = \underline{\underline{High}}$$

Sections at points C & D are not critical by observation.

Hoop tension in fabric at load bar:

N = pR = Hoop Load (lbs)/in.

$$p = \frac{511}{(2)(.063)} = 4055 \text{ psi}$$

R = t/2 = 0.0315 in.

N = (4055)(0.0315) = 127.7lbs./in.

Allowable Hoop Load = (100) (2) lbs./in.

$$M.S. = \frac{200}{127.7} - 1 = \underline{\underline{0.564}}$$

*Allowable load per inch, dacron cloth, 5.0 ounces
**Four layers of cloth

Gusset Shear Strength (Adhesive)

The adhesive utilized in the fabrication of the paraglider is a 3M EC-2135 Resin and EC-2134 catalyst. Tests conducted at the Ryan Aeronautical Company indicated that a minimum shear strength of 44 psi may be used for design. However, from experience and tests, it is established that the strength of these joints exceeds the strength of the parent material. For this reason, an analysis is not made for this glue joint.

Net tension at point A

$F = 110$ lbs. ultimate

$P_{allow} = 400$ lbs.

M. S. = High

Points B and C — Not Critical by inspection

Leading Edge Tail Cone

Lug Analysis: — Ref: Product Engineering May, 1950, page 113

149WZ00 -3 Tail Cone Fitting

Lug Analysis — Material: 6061-T6 alum. sheet

$w = 0.76$

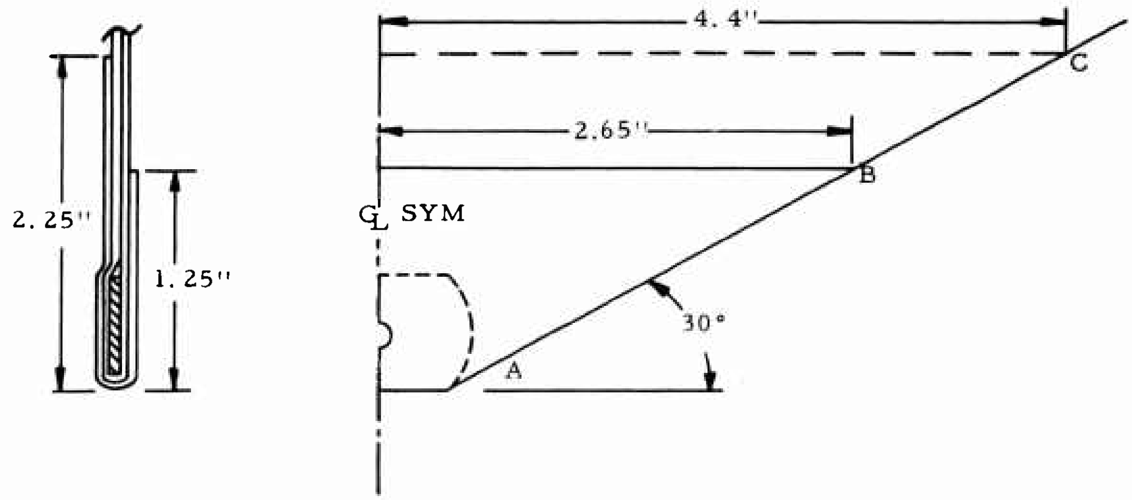
$D = 0.194 \qquad \frac{w}{D} = \frac{0.76}{.194} = 3.92 \qquad \frac{D}{t} = \frac{0.194}{0.125} = 1.55$

$a = 0.38$

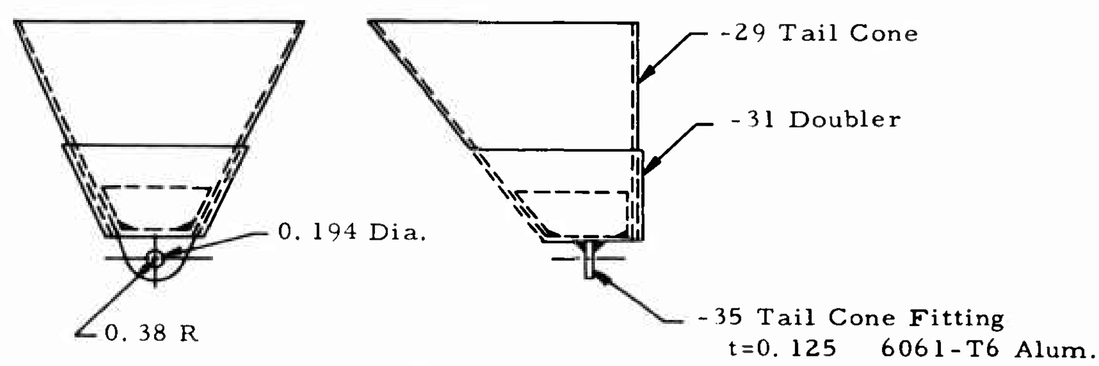
$t = 0.125 \qquad \frac{a}{D} = \frac{.272}{.194} = 1.40$

See diagram on page 64.

INTERMEDIATE GUSSETS



LEADING EDGE TAIL CONE ASSEMBLY



$$A_{BR} = Dt = (0.194)(0.125) = 0.0243 \text{ in.}^2$$

$$A_t = (W-D)t = (0.76 - 0.194)\ 0.125 = 0.0708 \text{ in.}^2$$

$$P_{tu} = K_t\ F_{tu}\ A_t \quad \text{(tension-net section)}$$

$$K_t = f(W/D)$$

$$= 0.30$$

$$= (0.30)(42000)\ (0.0708) = 893 \text{ lbs. allowable}$$

$$P_{BR_u} = K_{BR}\ A_{BR}\ F_{tu} \quad \text{(shear-bearing)}$$

$$K_{BR} = f(a/D, D/t) = 1.3$$

$$= (1.3)(0.0243)\ (42,000) = 1328 \text{ lbs. allowable}$$

$$P_y = C\ \frac{F_{ty}}{F_{tu}}\ P_{min}$$

$$P_{min} = P_{tu} = 893 \text{ lbs.}$$

$$C = P_{min}/\ A_{BR}\ F_{tu} = 983/1020 = 0.87$$

$$P_y = (0.87)\ \frac{(35,000)}{(42,000)}\ (893) = 647 \text{ lbs. (lug yield allowable)}$$

The load which is calculated in the following analysis differs from that on the apex suspension point in that the apex load includes a non-metallic fitting factor. Since the aft cone is aluminum, the fitting factor is not included.

Opening snatch force = 2415 lbs. limit

= 3620 lbs. ultimate

Load per line $= \frac{3620}{6} =$ 604 lbs. ultimate

Line convergence factor = 1.055

$\therefore$ Load per line = 604 x 1.055 = 631 lbs. ult.

$$M.S. = \frac{647}{631} - 1 = \underline{\underline{0.02}}$$

Leading Edge Tail Cone

The leading edge tail cone fitting is glued inside the dacron cone. There is an external dacron doubler to increase the hoop strength and to decrease the elongation. Any excessive elongation in the hoop direction may allow the tail cone fitting to slip out if the glue does not insure a positive attachment.

The tail cone and tube on the leading edge is attached by means of "finger" doublers. The effective shear lap area is approximately one-half of the circumference times the lap dimension. Additional external doublers are applied longitudinally to strengthen the joint further. These doublers are 1 inch wide and 4 inches long. The total shear strength of the joint is

$$P_{allow} = \left[(1/2)\ (\pi D)\ (1) + (8)\ (1)\ (2) \right] (45)$$

$$= 1143 \text{ lbs. shear allowable}$$

conservatively assuming that all of the tail cone fitting load is carried by the leading edge tube gives

$$P = \frac{pR}{2} + 631 = \frac{(4.8)\ (3.21)}{2} + 631$$

$$= 638.7 \text{ lbs.}$$

$$M.S. = \frac{1143}{638.7} - 1 = \underline{\underline{0.79}}$$

Membrane Splice (2-inch lap)

$$P_{allow} = (2)\ (44) = 88 \text{ lbs./in.}$$

$$N_h = 74 \text{ lbs./in.} \quad \text{Ref. Pg 57}$$

$$M.S. = \frac{88}{74} - 1 = \underline{\underline{0.19}}$$

Keel Tail Cone

All parts aft of the rear bottle mount are not structurally loaded. Therefore, they are not analyzed.

MS20115-3 Shackle

Load = 631 lbs. ultimate

Allowable = 920 lbs.

$$M.S. = \frac{920}{631} - 1 = \underline{\underline{0.46}}$$

Leading Edge Suspension Line Bridles

Hoop load in bridle = pR

Load on L. E. = (0. 25) (1. 06) (300)

= 79. 25 lbs. (lg)

= 238 lbs. (ultimate)

$$\text{Maximum distributed load} = \frac{1.2P}{L} = \frac{(1.2)\ (238)}{(22) \times (12)} = 1.08 \text{ lbs./in.}$$

Line load = (1. 08) (0. 250) (22) (12)

= 71. 2 lbs. ultimate

$$p = \frac{71.2}{1} = 71.2 \text{ lbs./in.}^2$$

Hoop load = (71. 2) (0. 50) = 35. 6 lbs. /in.

Allowable line load = 1200 lbs.

$$M.S. = \frac{1200}{35.6} - 1 = \underline{\underline{High}}$$

$$\text{Resolved bridle load} = \frac{71.2}{2 \cos 30^\circ} = 41 \text{ lbs.} \qquad \underline{\underline{\text{Not Critical}}}$$

Apex Analysis

An analysis of the apex design has not been included in this report. Time limitations and the extreme complexities of the detail design do not make practical an analysis at this time. To substantiate the structural integrity of the apex design, adequate static and dynamic tests were conducted.

FABRICATION

Fabrication commenced concurrently on the control platform, receiver/transmitter and the wing assembly. The Ryan Experimental Shop fabricated the wing and control platform assemblies, and Ryan Electronics fabricated the receivers and transmitters.

Weights

The wing system consists of the wing structural members, wing membranes, air bottle installation, glider lines, riser straps, and assorted hardware, for a total weight of 50 pounds.

The control platform includes the receiver, servo, 12-vdc power supply, 24-vdc power supply, transistor power supply, antennas, and associated wiring, for a total weight of 75 pounds.

The cargo container, including liner, cargo sling and straps, plywood pallet, and associated hardware, weighed a total of 55 pounds.

Wing Assembly

Figure 23 reflects the template layout of the membrane to keel section. The coated fabric is marked by utilizing various shop aid templates; it is cut with scissors, is cleaned with MEK (methyl ethyl keytone), and is bonded together with 3M EC-2134/EC-2135 adhesive.

Figure 24 shows a close-up of the leading edges, the keel, and the apex section prior to mating. Note the shop aid fixture in the left-hand leading edge.

Figure 25 is an overall view of the leading edges, the keel, and the apex section prior to mating.

Figure 26 shows a completed membrane assembly being prepared for the installation of the tube sections, i.e., leading edges, keel, and apex section. In the background, note the rolling tool used when bonding joints.

Figure 27 shows a completed wing with shroud lines attached and pneumatic assembly installed. Note the fairing tail cone on the aft end of the keel.

Control Platform

Figure 28 shows the control platform sheet-metal work with the wing pan in the center; the servo mount, the traveler guide track, and the battery box in the after end; and the electronics section with antenna mounts in the forward end.

The platform is fabricated from .063-inch aluminum alclad sheet, which was formed in sections and riveted together.

Figure 29 shows the after end of the control platform with the rotary-wound control lines, the servo motor, the mechanical latch installation, the manual and homing limit switch bank, and the 12-volt dc power supply.

Figure 30 shows the forward end of the control platform with the antennas installed, the receiver and its power supply, the transistor power supply, and the antenna coaxial barrel tee connectors.

Figure 31 shows the transmitter power supply on the left, the 133-megacycle transmitter in the center, and the 133-megacycle receiver with its power supply mounted on top on the right.

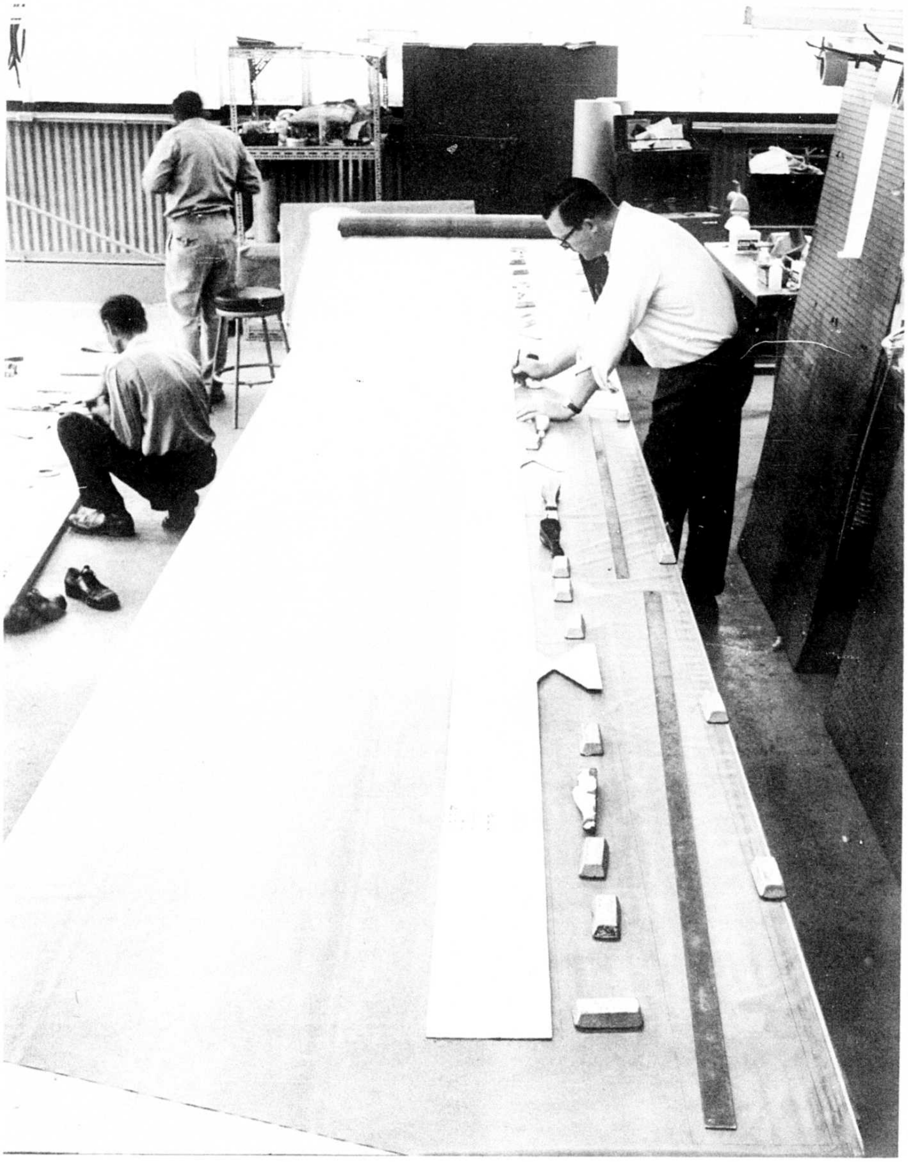


Figure 23 Template Fabrication Marking

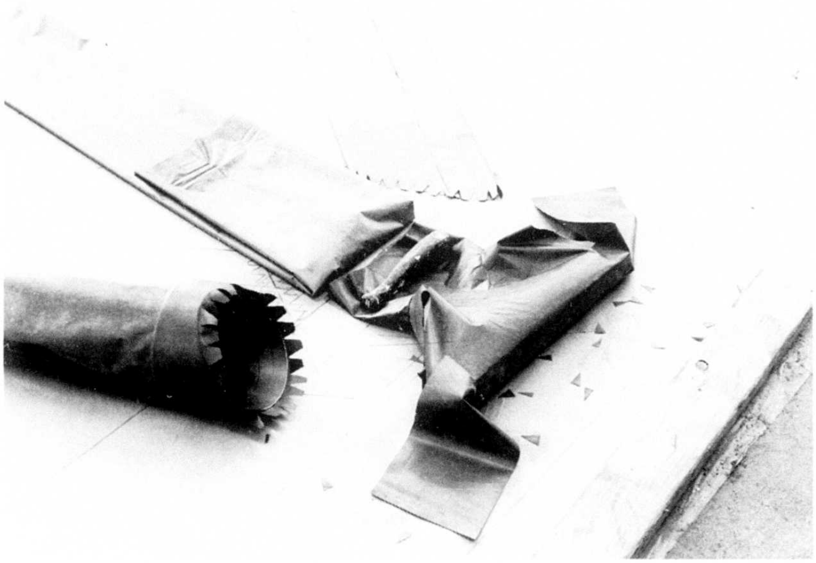


Figure 24 Leading Edge and Keel, Apex Section (Close-up)

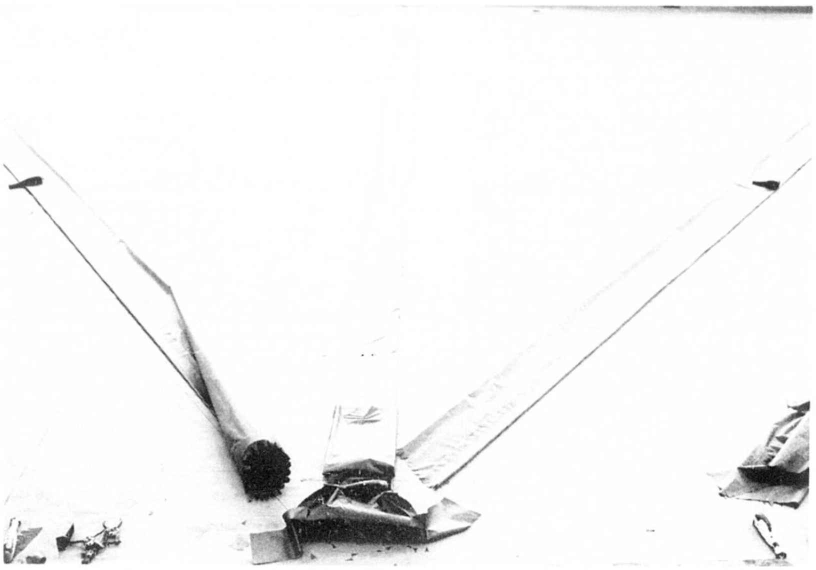


Figure 25 Leading Edge and Keel, Apex Section (Overall)

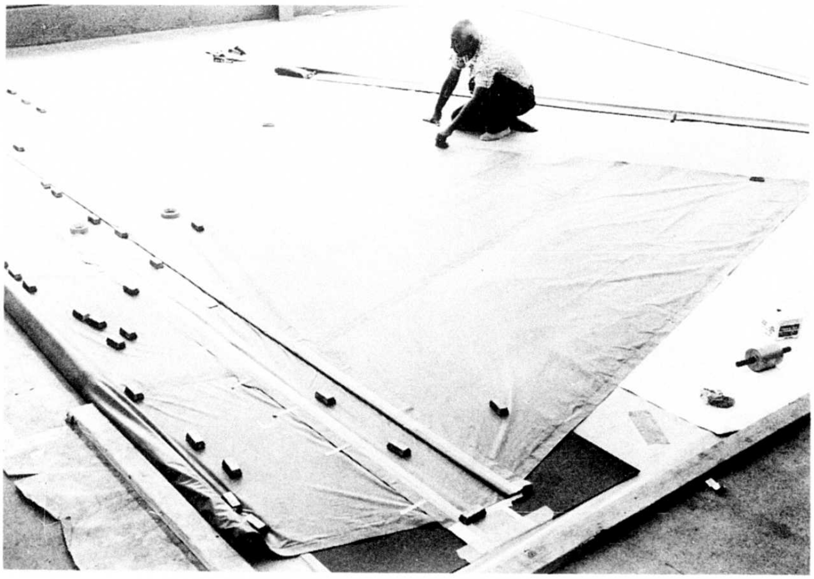


Figure 26 Membrane Section Complete

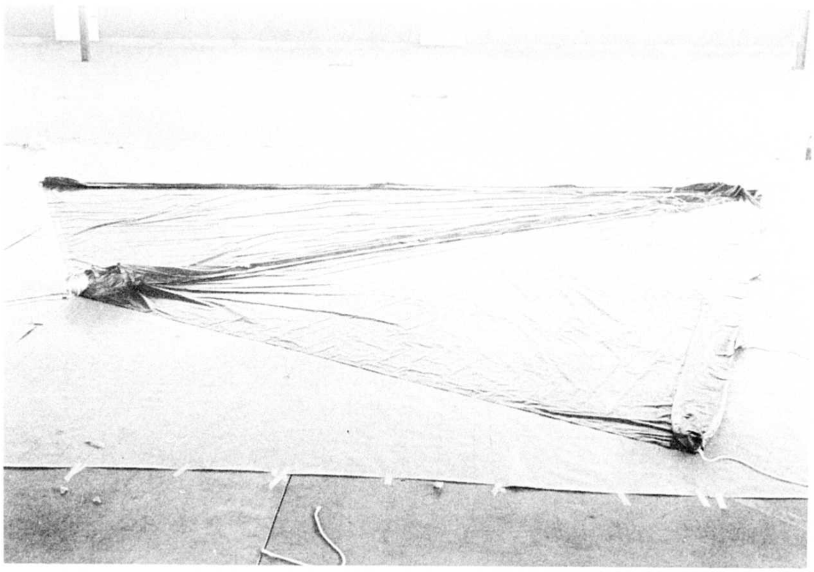


Figure 27 Wing Assembly Complete

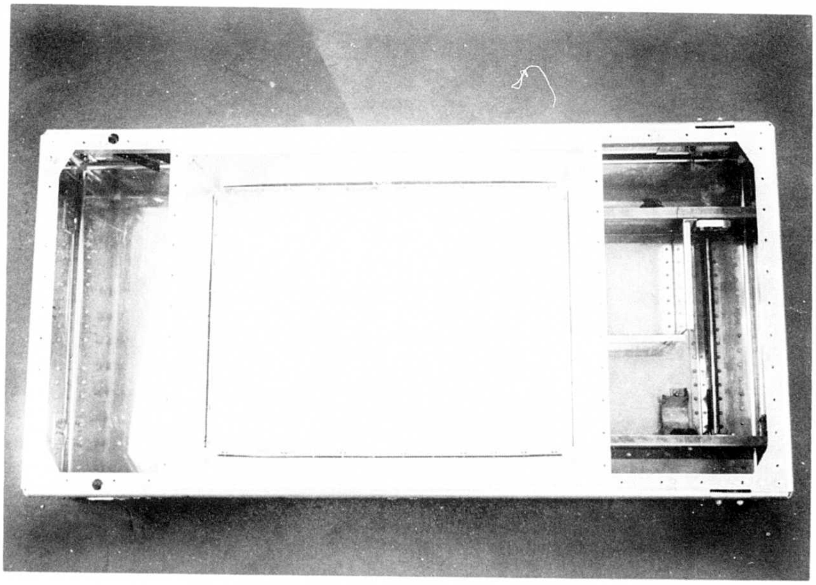


Figure 28 Control Platform Shell

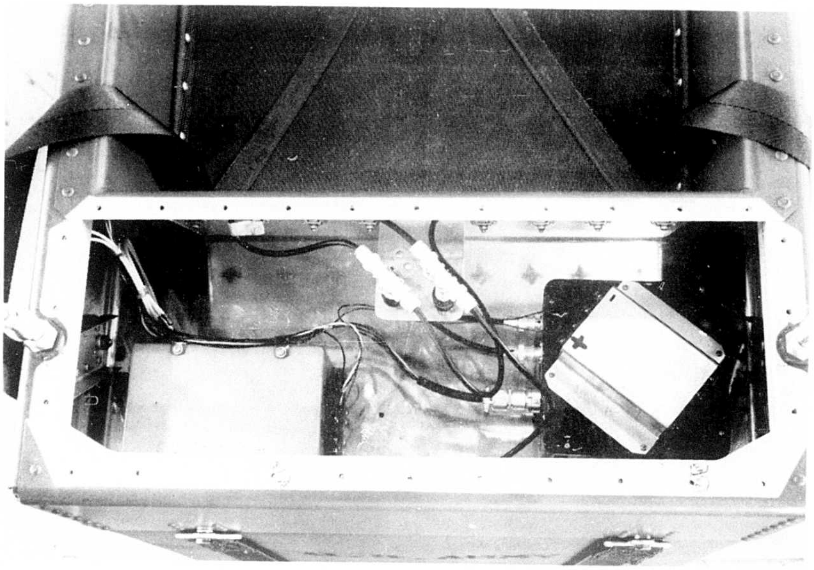


Figure 29 Forward Section of Control Box

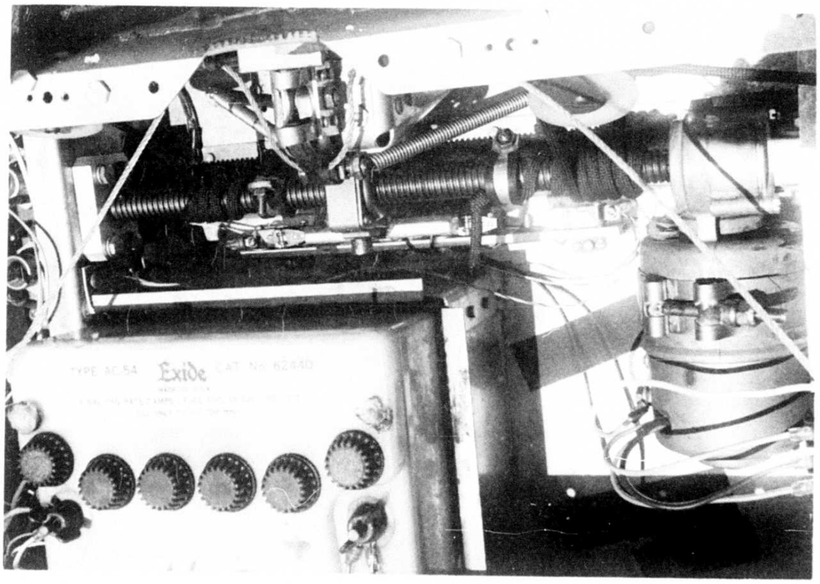


Figure 30 Aft Section of Control Box

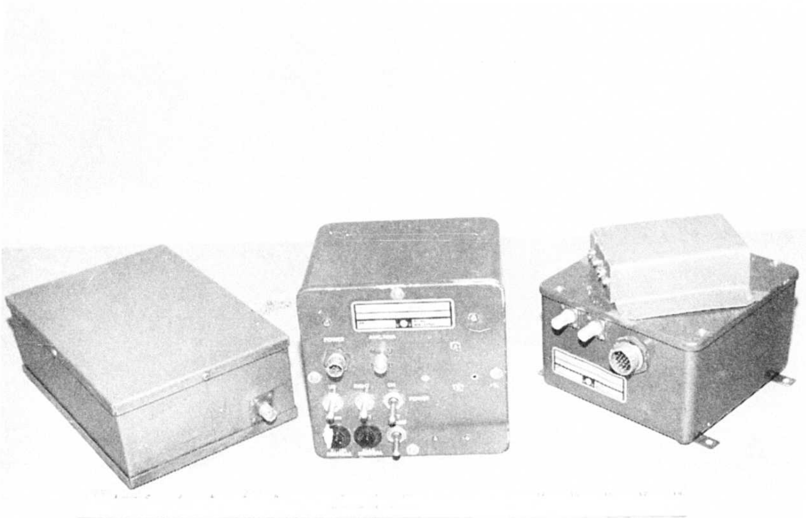


Figure 31 Electronic Equipment and Power Supplies

FLIGHT TEST

Wing Packing Procedure

System reliability during the deployment sequence is dependent on the method of packing the wing and stowing the suspension lines. The method used must be systematic and such that the packing procedure may be readily repeated.

The photographs shown in Figures 32 through 40 depict a typical packing procedure. Modifications to the packing method and configuration were made during the test program in the interests of improving product reliability. These changes are noted in Table 1 and are primarily concerned with line lengths and stowage techniques.

Detailed procedures for packing are presented in Reference 3.

Figure 32 shows the wing on the floor with the vacuum pump attached to the bottle assembly to evacuate all the air from the inflatable tubes to facilitate packing.

Figure 33 shows the suspension lines on the left-hand leading edge drawn away from the wing with the left-hand wing membrane pleated. Pleating starts adjacent to the keel, each pleat being 8 to 10 inches wide.

Figure 34 shows the wing fully pleated.

Figures 35 through 36 show the wing in the "W", or accordian, fold after the pleating operation is completed.

In Figures 37 through 38, the sleeve is inserted into the wing storage container pan.

As shown in Figure 39, the corner flaps are then folded over the sleeve and are restrained by three thicknesses of 80-pound break line.

The aft lid of the control box is then bolted on and both forward and aft reefing rings (3 each) are positioned in the latches. A 750 pound line with a 6 second reefing cutter is attached to the latch runaround cable to insure simultaneous release. The line is then tensioned by means of a turnbuckle. The forward lid

is then secured. Surplus glider and parachute lines are stowed on the box lids. The glider lines from the six restrained rings are fed from the top of the control box, whereas the parachute portion of the lines feed from the wing.

The final packed wing, as shown in Figure 40, illustrates the antennas restrained by the 80 pound break line and the reefing cutter pin secured to the static line.

A six foot static line was used in conjunction with an eleven foot sleeve for all launch aircraft except for the C-47, which used an eleven foot static line and an eleven foot sleeve.

Test Procedures

Test procedures for this program followed closely those established for parachute testing and from experience gained during previous inflatable flexible-wing test programs.

The following fixed-wing aircraft were used as launch vehicles:

U-1A	Otter
U-6A	Beaver (L-20)
CV-2A	Caribou (AC-1)
C-47	Dakota

One drop was conducted using a UH-1 Iroquois (HU-1) helicopter. All drops were made at a predetermined altitude, heading, and airspeed, with launch off-sets which varied from directly overhead to 2-1/2 miles from the drop zone target.

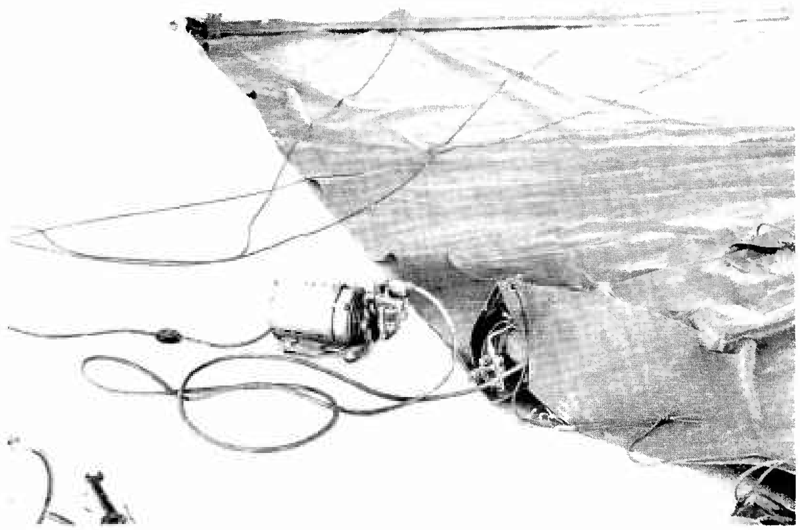


Figure 32 Wing Packing - Tube Evacuation Prior to Pleating

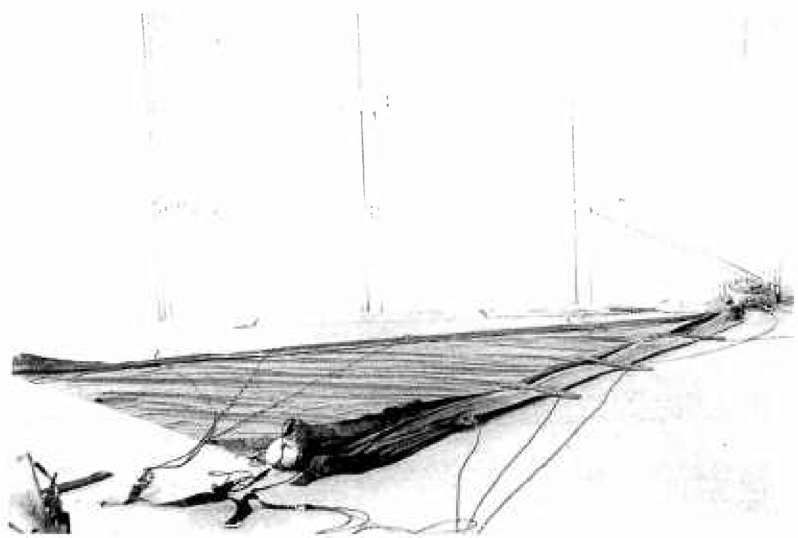


Figure 33 Pleating Operation - Initial

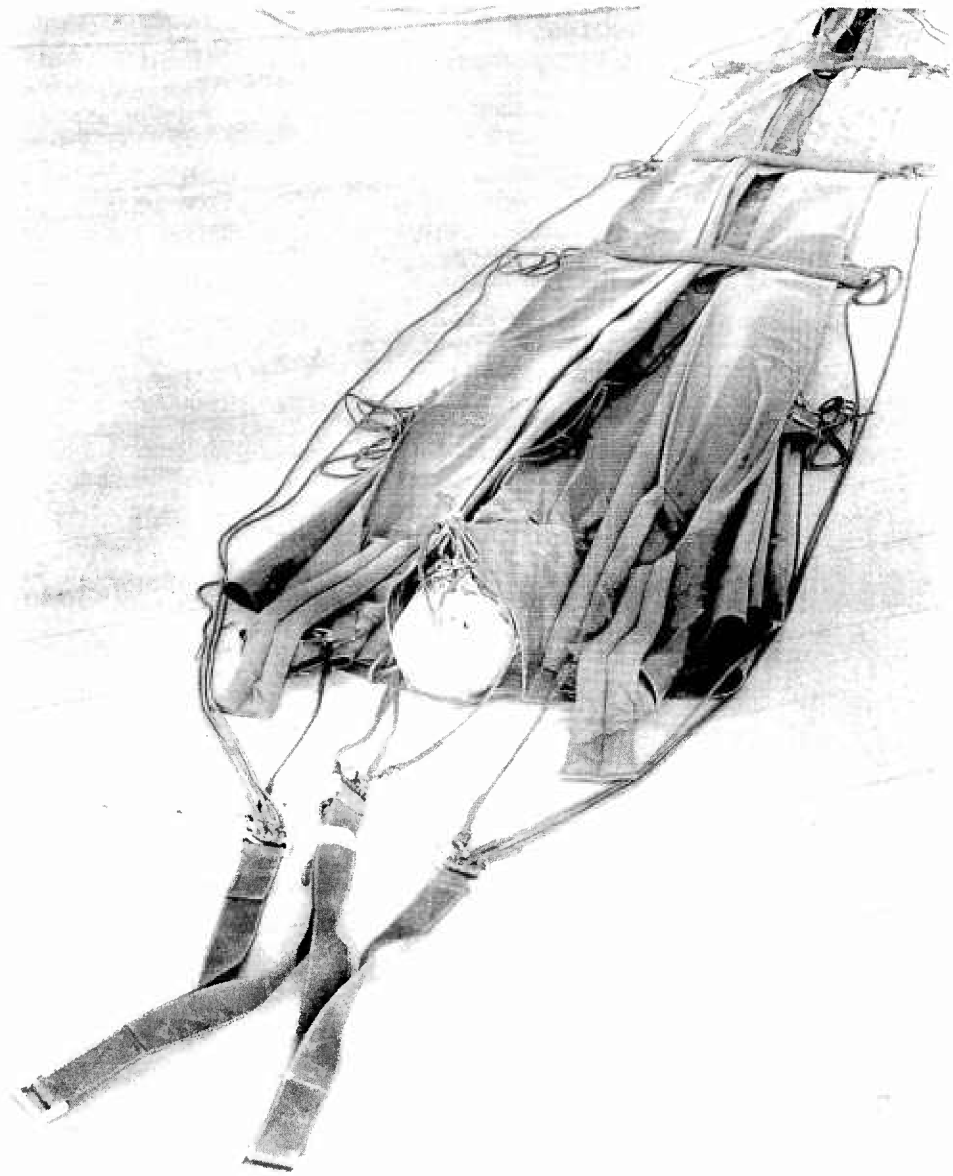


Figure 34 Pleating Operation - Complete

Figure 35 "W" Fold - Complete

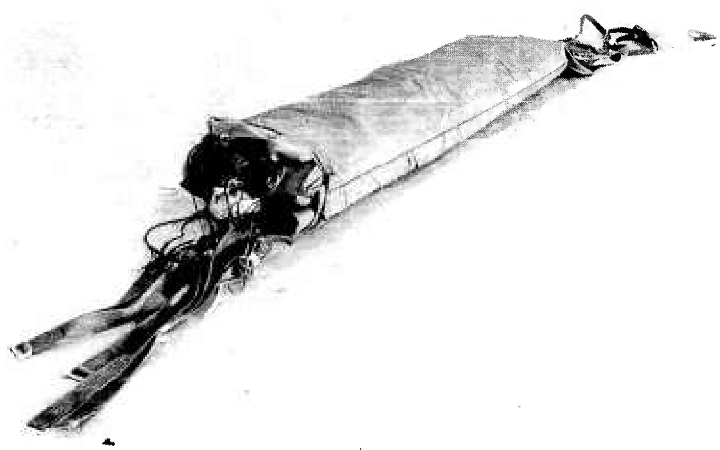


Figure 36 Wing Stowed in Sleeve

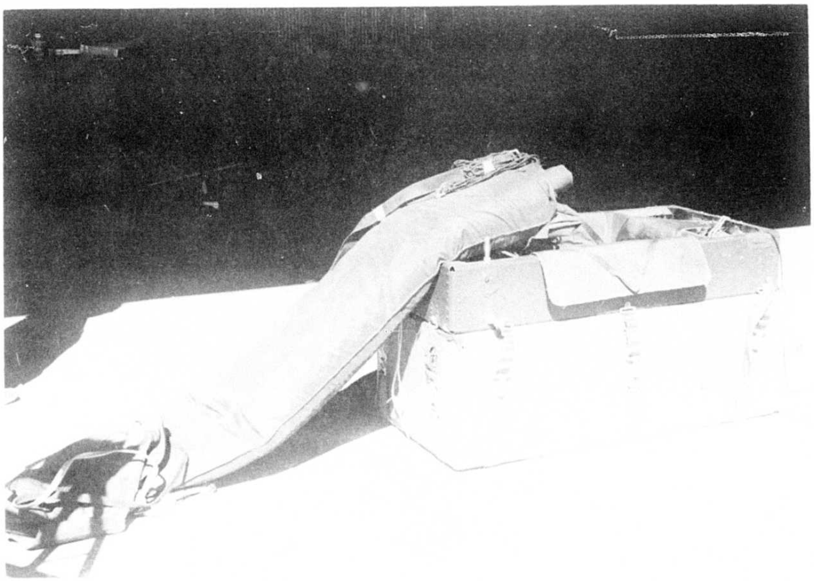


Figure 37 Wing Alignment to Control Box Storage Pan

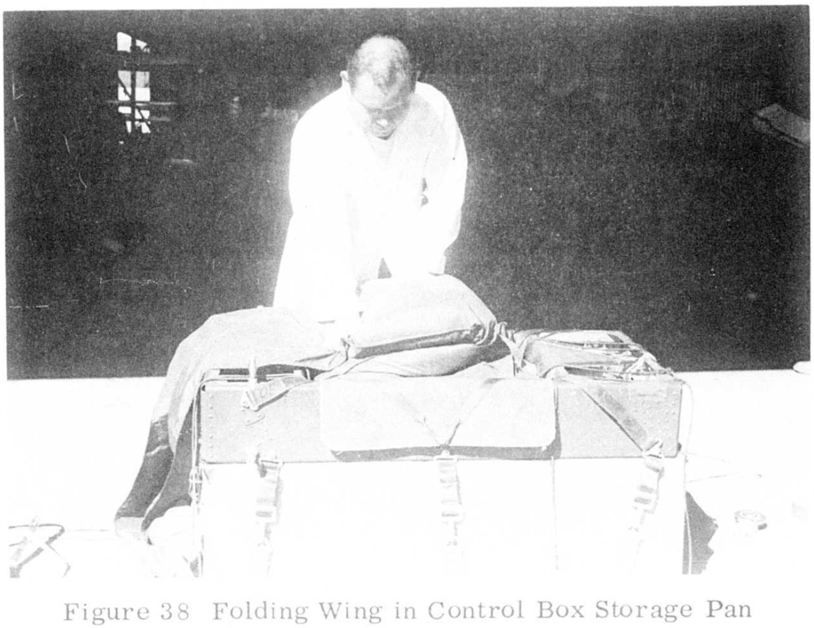


Figure 38 Folding Wing in Control Box Storage Pan

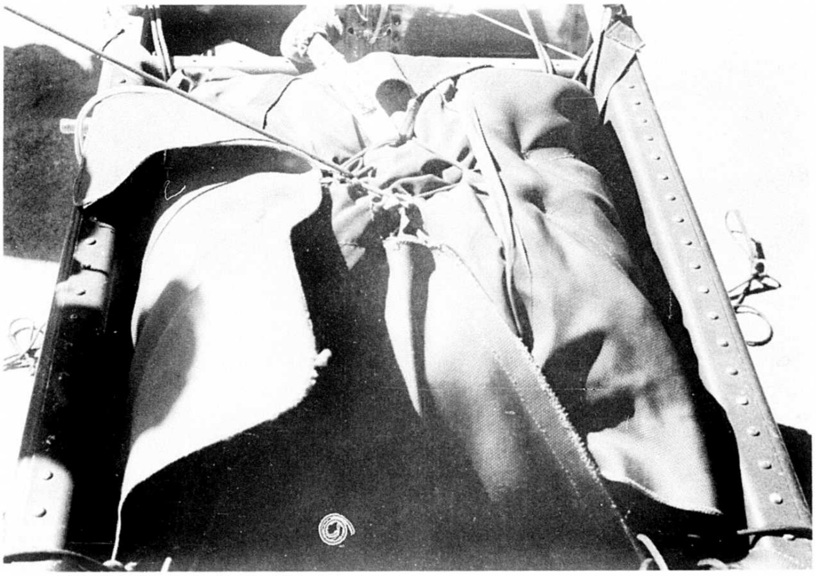


Figure 39 Securing Corner Flaps Over Stored Wing

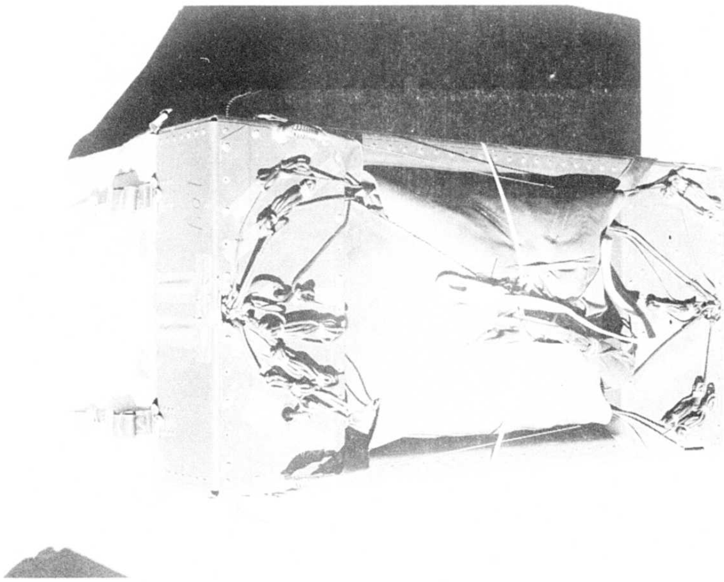


Figure 40 Wing Storage - Complete

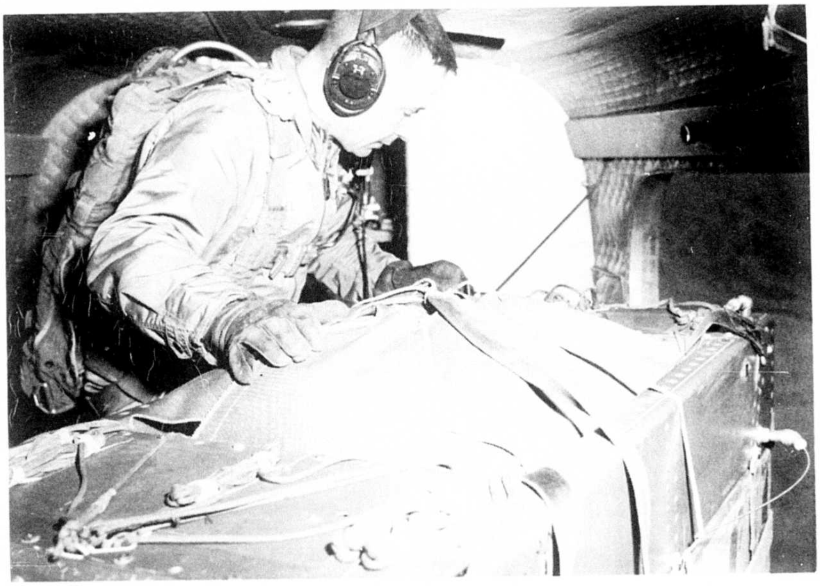


Figure 41 PDG Launch Procedure - Remove Parachute Reefing Cutter Safety Pin

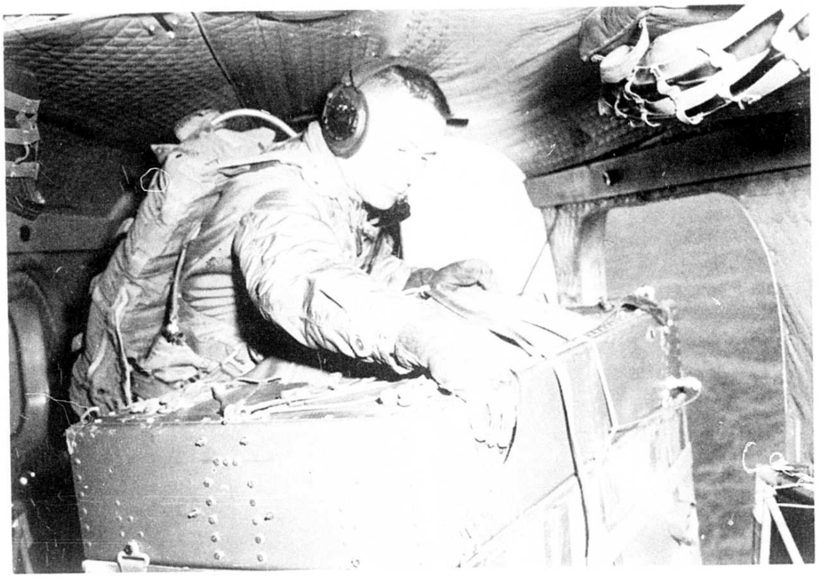


Figure 42 PDG Launch Procedure - Turn Master Power Switch "On."

Figure 43 PDG Launch Procedure - Unfasten Tiedown Strap

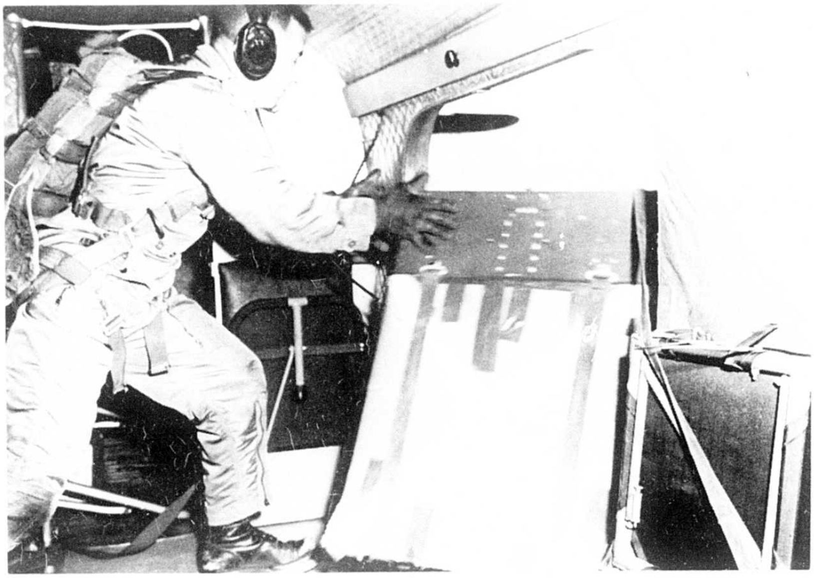
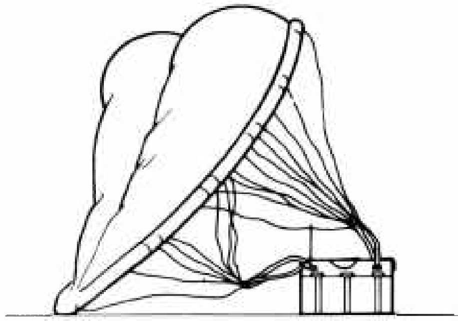
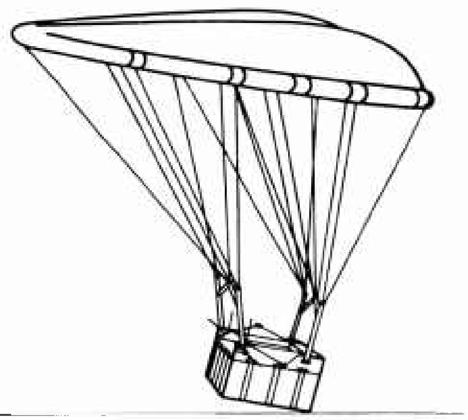


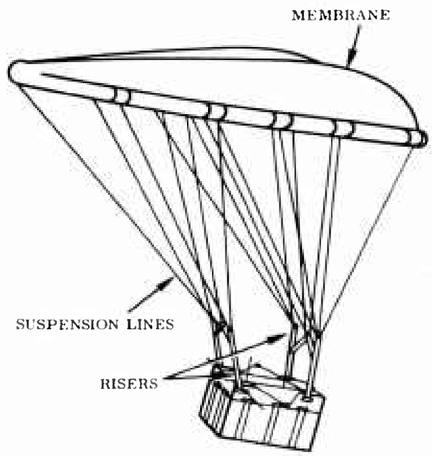
Figure 44 PDG Launch



PHASE NO. 9
LANDING OF CARGO CONTAINER
AND FLEXIBLE WING



PHASE NO. 8
CARGO CONTAINER IMPACTING



PHASE NO. 7
FLEXIBLE WING INFLATED AND IN
PREDETERMINED GLIDE PATH

FLEXI
FRO

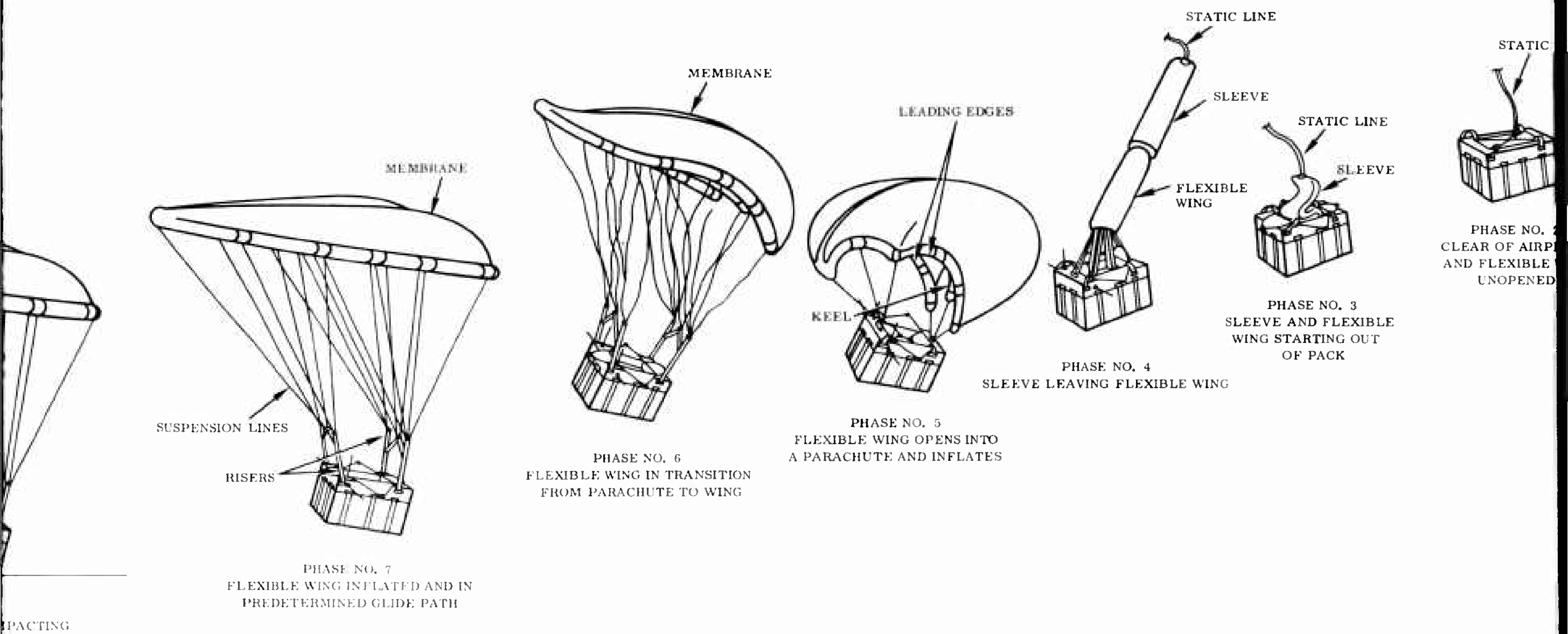


Figure 45 Glider Launch -

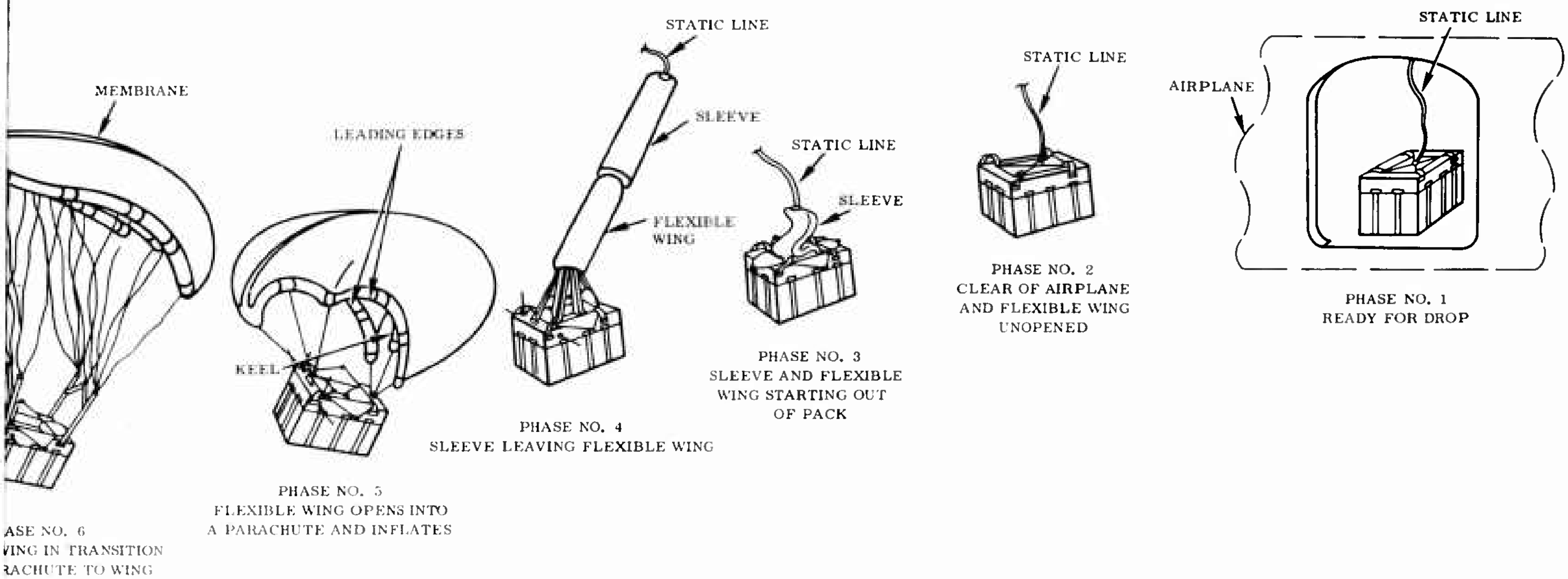


Figure 45 Glider Launch - Deployment Sequence

3

The ground control unit was utilized for all drops except for those structural investigation flights in which the paraglider was purposely restrained to remain in the parachute mode throughout the flight. For a normal flight, no ground-to-air checks were deemed necessary prior to launch. Instead, both aircraft commander and jump master were briefed for the complete procedure prior to takeoff. The paraglider was launched upon the completion of a countdown by the launch aircraft commander. Figures 41 through 44 depict the steps of the launch procedure:

With parachute reefing cutter safety pin REMOVED and master switch ON, estimate the launch point, conduct countdown, and launch. System operation during the deployment sequence and glide mode is depicted in the operational sequence drawing, Figure 45 . The paraglider pack is opened by a static line and the sleeve is removed. The static line, which is attached to the sleeve, pulls the wing out of the saddle storage pan after breaking open the 80-pound test line. Upon complete suspension line stretch, the sleeve is pulled off the wing. Initially, the wing is deployed in a configuration resembling an unsymmetric parachute. Suspension lines are reefed to appropriate lengths, forming the wing into the parachute shape. The wing is held in the parachute shape to decelerate and stabilize the system. The latches restraining the reefed suspension lines are then released by a 6-second time-delay reefing cutter, activated by sleeve removal. The tube inflation operation is begun while the wing is still in the parachute mode, this system also being activated by a separate 1.5-second time-delay reefing cutter.

Each test drop during this program followed the flight sequence outlined above. Variations in test configuration involved changes in line stowage methods, wing folding and stowage methods, and reefing cutter and cutter time delay; increased launch airspeed; and a build-up to a maximum gross weight of 425 pounds (300 pounds payload).

During all drops, motion-picture coverage was obtained in various combinations of ground-to-air and air-to-air. Many drops were covered by cine-theodolite tracking stations which provided flight path information, such as rate of descent, turning radius, rate of turn, and glide ratio.

Test Results

A total of 139 air drops of the PDG wing were conducted at the U. S. Army Yuma Test Station over the period from 4 October 1962 to 1 March 1963.

The changes incorporated prior to each of the flight test operations are presented chronologically in Table 1. Table 2 presents a chronological listing of the wing and payload configurations and launch conditions for each of the flight test operations. Pack method configuration details are presented in Table 3. The shroud line description is contained in Table 4. The original and subsequent paraglider line lengths are presented in Tables 5 and 6 for all wing configurations that were utilized during this program.

The initial phases of the test program consisted of air drops of a 13-gusset wing rigged for a 30-degree angle of attack. (See Figure 14 for glider line nomenclature.) After FTO 41, 13-gusset wings were no longer utilized in the program; 16-gusset wings were used exclusively thereafter. The 16-gusset wing provided better load distribution on the aft glider lines. The angle of attack remained at 30 degrees throughout the test program, with the exception of flight test operation (FTO) 28, which was rigged for a 34 degree angle of attack. No flight control response was apparent on that flight.

Packing and Deployment

Various packing procedures and PDG deployment techniques were investigated throughout the test program. Five drops were conducted utilizing a restrictor, which was added to the air supply line when the paraglider was equipped with a 125-cubic-inch air bottle. The purpose of the restrictor was to slow the rate of air flow into the inflatable tubes in an attempt to reduce the possibility of tube

kink and to prevent the nose of the wing from folding or tucking under the remainder of the wing during transition from parachute mode to wing mode. Satisfactory results were not obtained using this modification. The release mechanism used to initiate the two principal phases of the deployment sequence was activated by Class 2 pyrotechnic reefing cutter charges. The air bottle pressure was released and inflation of the structural tubes commenced; 1.5 seconds after launch, static line became taut. Forward velocity of the vehicle was nearly dissipated by 4 seconds after the launching static line had become taut, at which time the second cutter fired, releasing the parachute line restraining rings from the latches, and a glider was formed. No significant difference in deployment problems was apparent from use of either the 4-second cutter for glider formation, although the 6-second variety was used predominantly throughout the PDG flight test program because of availability.

Structural Build-up

Initially, the air bottle pressure used for wing inflation was 4,000 psig in a 125-cubic-inch bottle. Forty-two drops were conducted in this air bottle configuration with 90 percent successful operation of the inflation system. There were 13 instances of line entanglements, 4 late wings, and 5 other glider problems unrelated to air bottle operation. The capability of inflating the keel and leading edges appeared to be marginal, according to postflight pressure checks. There were six instances of nose tuck from which the glider did not recover.

In order to increase the structural rigidity; to reduce the time to inflate; to employ lower bottle pressures, and to overcome line pickup tendencies and nose tuck, a higher capacity 205-cubic-inch air bottle was introduced midway in the flight test program. Those flights which utilized this air bottle are denoted in Table 2 by bottle pressures less than 4,000 psig. Of the 89 flights made using this larger capacity air bottle, 81-percent-successful bottle operation was attained, the rate of line pickups was reduced from 21 percent to 7 percent, and nose tuck occurrences reduced from six to one. There were six instances of glider line entanglements; nine late wings; four occasions during which the air bottle tore loose from the wing; two instances in which the air bottle reefing cutter safety pins were not removed, and one failure of the inlet air valve upon air bottle activation.

The increase in the number of late wings after incorporation of the large capacity air bottle was due to faulty operation of the high-pressure release pin. Slight imperfections in the release pin caused the pin friction to be much larger than

the force exerted on the pin during the deployment sequence. This problem was alleviated by better inspection procedures of the release pin and by the addition of a nylon pocket bottle fitting collar. After this additional modification, there was only one instance of a late wing.

The forces required to cause the air bottle to tear away from the wing during deployment were caused by the opening shock loads at maximum allowable launch airspeeds and payloads. Bottle separation may have been caused by a launch during which the box experienced a high rate of tumble.

On the flight in which the entry air valve failure occurred, the glider exhibited a loss of wing air pressure immediately upon formation of the parachute mode. Postflight inspection revealed that the break at the neck was clean. The hexagonal head of the entry valve was observed to have been forcibly impressed on the air bottle protective cap. The cap also appeared to have inflicted a dent on the control box lid of some magnitude, apparently at launch, since no inflation of the wing occurred. All other such components were inspected and found to be free of any fatigue indications. It was therefore concluded that a contact between the control box and the air bottle during launch was the primary cause of the failure.

Loss of tube pressure after launch due to line burns on the tube inflicted during deployment was substantially reduced by incorporation of an additional layer of tube material on the underside of the structural members. Upon completion of this field change, only one flight exhibited loss of pressure during flight. Prior to this change, there were four flights in which in-flight air pressure was lost after glider formation.

Twelve drops were conducted with the wing in the original configuration. Oscillation of the parachute was usually evident during the parachute mode. Although gliders were obtained on five occasions, packing and deployment problems were present on four of these five flights. The seven unsuccessful drops involved line pickup and/or line entanglements. After these first twelve drops, the No. N1 parachute nose line was increased 3 feet (from 6 feet 8 inches to 9 feet 8 inches) and the No. L2F and R2F parachute lines were decreased 1 foot (from 11 feet 10 inches to 10 feet 10 inches). This modification, when utilized at 65 KCAS, appeared to be satisfactory. Sixteen of twenty-five drops which were configured for this parachute modification were successful. Drops at increased launch speeds of 75 KCAS, however, were unsuccessful as exhibited on the next four drops, which resulted in three reefing cutter line failures and one riser strap

failure. Increasing the 1, 000-pound test nylon reefing cutter line to a 3, 000-pound nylon strap did not solve the problems involved with the higher launch airspeeds but created an additional problem of tuck.

Subsequent changes in the parachute configuration and latch system were incorporated in the latter part of the flight test program, which permitted launch speeds of 95 KCAS with a 200-pound payload or 85 KCAS with a 300-pound payload. In this configuration, the parachute lines were shortened 5 feet (as noted in Table 6), the use of the risers as structural members was eliminated during the parachute mode, and two latches (one forward, one aft) were attached to the control box and rigged to release all six parachute rings simultaneously. The glider line portion of the parachute lines was stowed on the control box, as shown in Figure 40. This structural modification permitted higher launch speeds due to reduction in opening shock load by restricting the mass rate of air intake to the parachute. With lines L5 and R5 only 18 inches long, the control box and payload frontal area appeared to contribute to the reduction of the opening shock loads, with the resultant satisfactory flight operation in the higher speed regime. Separation into two different attach points of the fore-and-aft lines during the parachute mode provided a satisfactory restoring force to resist any significant moment build-up between the payload and parachute twisting during deployment.

In addition to reduction of the shock loads, line entanglement problems were reduced significantly by means of a double line stowage incorporated at the time of the control box latch modification, in which the glider lines stowed under the gussets were separated within heavy rubber bands into two small groupings instead of the original single large grouping. This grouping of smaller masses of line reduced the possibility of shaking the coiled glider lines free during the parachute mode opening shock loads.

Prior to incorporation of the control box latch modification, eight drops were conducted with wing 101 in the parachute mode only. While the configuration differed from the latch modification, in that the fore-and-aft risers were used with parachute lines 6 inches shorter, structural capability at higher airspeeds was investigated to absolute limits without recourse to utilizing flyable gliders. These flights revealed that to launch the PDG vehicle above a 200-pound payload at 95 KCAS was approaching the maximum structural design limits. No change in structural capability of the vehicle was noted when the PDG was launched either at low altitudes or at 9, 000 feet, the highest launch altitude.

The final configurations as established through this flight test program were the I, J, and L pack configurations. These methods are nearly identical. See Table 1 for an explanation of the differences, starting with item 108 for the J pack configuration and item 137 for the L pack configuration. Sixty-five drops were attempted in these configurations, thirty-nine of which formed satisfactory gliders. Structural difficulties were encountered on eleven of the drops which were conducted at launch airspeeds of 90 and 95 KCAS. The remaining fifteen drops experienced difficulties such as line entanglements and, during eleven launches, four instances of an unpressurized wing because of binding of the air bottle pressure release pin. This binding problem was alleviated by instituting inspection procedure to examine the release pin for signs of galling or nicks.

Flight Control

The original flight control system employed at the beginning of the PDG flight test program consisted of a ground radio transmitter, the in-flight receiver, and an electrical motor system which provided c.g. shift by pulling in or letting out the two aft risers. This system was applicable to either manual control or the homing mode.

During the first thirty drops, there were fifteen flights in which glider control was attempted utilizing this system of c.g. shift. Of these thirteen, none of the flights exhibited a positive response to manual control command inputs. Steady-state rates of turn attainable with this flight control configuration were approximately 3 degrees per second or less, and were due to wing trim asymmetry.

A keel line length modification was incorporated on all 16-gusset wings after FTO 30 in which the lines were shortened to lower the keel. The aft end of the keel was shortened the greatest amount. The purpose of this change was to evaluate the new configuration for additional lifting surface response and directional stability. From this change it appeared that the glider was experiencing less trailing edge flutter, and the modification was retained for the remainder of the program.

To increase the rate of turn and simultaneously to reduce altitude loss due to turns, the control system was modified to provide control by displacing only the two aft glider lines (control lines) as outlined in Description of Test Program. This technique produced a bending of the leading edges between the last two gussets, giving an "aileron effect" to the wing. For example, pulling in the

right aft glider line and releasing the left, turned the paraglider to the left. Rates of turn obtainable with this revised system varied between 2 and 25 degrees per second, but a symmetric wing averaged roughly 10 to 15 degrees per second. The control lines were shortened 3 inches from the normal length to obtain a more positive response of the aft wing panels to control line displacement.

As a result of this control line modification, of the seventy attempts at manual control response during the glider mode, forty provided satisfactory control. Fifteen drops resulted in partial control and fifteen displayed erratic or no significant response to command inputs. Partial control was apparently due to asymmetric rigging of the wings.

During the early attempts at manual control with the aileron-type control surface, the control lines were normally "doubled"; that is, the control line was wound around a pulley on the traveler and brought back to the side of the control box, where it was dead-ended, creating a double advantage. However, on seven drops, the control lines were not dead-ended at the control box side but were threaded through still another pulley and dead-ended on the pulley, creating a triple advantage. This technique performed satisfactorily on three flights, two of which, however, resulted in traveler malfunction prior to completion of the flight.

Homing was attempted unsuccessfully three times prior to incorporation of the control line aileron modification; twenty times after the change, and eleven more times during the reliability and follow-on programs. During these twenty times, only one flight in the control line mode appeared to exhibit satisfactory homing characteristics. On that flight, the rate of turn was estimated at 3 degrees per second, and four changes of direction by the glider were observed as the glider approached the target. It was apparent that because of the relatively slow rate of turn, traveler response speed and glider yaw rate were compatible for this flight. Glider target-seeking oscillations in yaw while in the homing mode on this flight varied between 20 to 30 degrees to either side of the intended flight path.

Flights in which yaw rates above 10 degrees per second existed encountered divergent homing mode oscillations due to the relatively long time required for the traveler to establish a reversal of direction. Prior to launch, the traveler was set to a neutral position where it could move 8 inches to the right or left. The time required to achieve full left or right turn from neutral was normally 10 seconds. Yaw rates of 10 to 15 degrees per second resulted in divergent

oscillations wherein the traveler motion arrested the turn only after the glider had turned more than 90 degrees from its heading to the target. Higher yaw rates produced complete circles.

Between FTO 92 and 120, two more attempts at homing were attempted, but without response. On FTO 121, the airborne flight control system was modified to the rotary wrap system in which control line displacement was achieved by wrapping the line directly around the screw jack, displacing ±9 inches of control line in the homing mode and ±17 inches in manual control. This change increased the control line displacement rate from 1. 6 inches per second to approximately 8 inches per second. What was considered a normal full rate of turn could be achieved from the neutral position in approximately 2 seconds. Between FTO 121 and 139, nine more attempts at automatic homing were conducted with the rotary wrap modification installed. Of these nine flights, two were unsatisfactory because of electrical circuit discontinuities, caused by foreign object interference. The other seven exhibited acceptable homing characteristics in which the maximum glider yaw rates appeared to be between 10 and 25 degrees per second. Glider target-seeking oscillations in yaw while in the homing mode on these flights varied between 20 and 60 degrees, on the average, to either side of the intended flight path. Three of these successful flights were permitted to remain in the homing mode until impact, averaging 400 feet circular error of probability (CEP) from the transmitting antenna. Insufficient data was available to determine satisfactorily the close-in flight characteristics of the glider in the homing mode.

The impact radius obtained with the transmitter operating in the manual control mode while controlling well-trimmed gliders varied between 8 and approximately 600 feet with a CEP of 185 feet. The skill required by the ground controller to achieve an acceptable CEP for a PDG impact was greatly reduced upon incorporation of the rotary wrap modification, since the lead time required to turn the glider from a rate of turn in one direction to a rate in the other was reduced from 5 to 10 seconds to approximately 2 seconds.

The distance, in feet, from the point of impact to the target/transmitter for 22 air drops under manual and auto-homing control is shown below:

Radius, feet	600	500	300	200	100	50	25
No. of Drops	22	21	17	13	9	8	3

Of these 22 drops, 3 impacts were made with the transmitter in the homing mode in which the paraglider impacted at distances of 600, 420, and 185 feet respectively.

Studies conducted by the Ryan Simulator Laboratory on PDG homing characteristics indicate that damping of homing oscillations could best be achieved by:

1. Utilization of a lead signal to initiate roll-out before the nose of the glider passes through the homing track.

2. Increasing the rate of roll through an increase in control line displacement rate.

Incorporation of the rotary wrap control system provided fair glider roll response to the homing mode, but insufficient time was available to install and evaluate a modification to provide lead to the flight control system.

Evaluation

The results of this test program are discussed and evaluated under the following five catagories:

1. Packing and deployment
2. Opening loads
3. Performance and control
4. Landing loads
5. Interpretation of measured and predicted glider performance.

Ciné-theodolite flight data consisted of three reels of film, one from each of the three tracking stations encircling the Yuma Test Station drop zone. Each frame of the film contained azimuth and elevation data to define the flight track. The three theodolites were synchronized by a master timer.

1. Packing and Deployment

During the course of the test program, a continuing evaluation of the packing and deployment sequencing took place. The final configuration resulted in a packing method and configuration which produced 41

successful drops out of 68 attempts. During the last 13 drops, 10 were considered successful.

The packing method employed for the last 68 drops was the "W" packing method, involving the I, J, K, and L pack configuration, in which minimum length parachute line lengths were used. The results obtained using this final packing method indicated that the structural integrity of the paraglider system was acceptable for utilization at the maximum design launch gross weight of a 300-pound payload at 85 KCAS or a 200-pound payload at 95 KCAS at altitudes up to 9, 000 feet. Additional testing is required to investigate the merits of the L pack configuration method of line stowage which could further reduce the occurrence of line entanglement during air drops.

2. Opening Loads

High opening shock loads which exceeded structural limits usually resulted in damage to parachute lines, parachute rings, gussets, or riser parachute latches. These deformations or failures continued to be a problem at launch airspeeds above 65 KCAS until the final "W" pack method and configurations I through L, with associated shorter parachute line lengths, were incorporated. These configurations lended further credence to the theory that a smaller parachute opening would create less opening shock loads and a longer parachute filling time, because, despite the fact that less opening shock energy absorption was available in this later version with the elimination of much of the parachute line length and all of the risers during the parachute mode, it became possible to expand the structural envelope from 65 to 95 KCAS. The resultant flight envelope is presented in Figure 46. The percentage of drops in which the opening shock loads were successfully withstood for a 300-pound payload at 85 KCAS was 67 percent and was 89 percent for a 200-pound payload at 95 KCAS for attempted launches of 3 and 9 times, respectively.

The L pack configuration involved the individual stowage of each glider line in approximately 6-inch lengths by restraining the glider lines between two parallel elastic bands spaced 5 inches apart and stitched to permit passage of a loop of line between each two stitches. The elastic bands are stitched to portions of the dacron polyester material; they are then bonded to either the wing membrane or structural member as space

permits. Incorporation of the L pack method would preclude the premature release of long lengths of glider line by restraining the lines such that they would be released by demand only through application of a steady load.

3. Performance and Control

Data were obtained which demonstrated the response of the Precision Drop Glider while in normal flight. The test data and a landing impact CEF show that the PDG is a highly maneuverable paraglider system which can deliver a high percentage of the air-dropped cargo close to the perdetermined landing site.

Glide performance presentations and response curves to flight control system outputs were obtained through the reduction of ciné-theodolite tracking film. Figures 47, 49, and 51 present altitude versus time plot for three different air drops. Figures 48, 50, and 52 exhibit the ground path of the paraglider during descent. All seven of these plots contain the wind effects experienced by the glider in flight. Table 8 presents a summary of the reduced ciné-theodolite data.

Table 8 shows that the average minimum radius of turn varied between 200 and 400 feet for FTO 52, 77, and 84, in which the "double" control configuration was utilized. No. L5 and R5 glider line control configuration flights, in which the wings appeared to be well trimmed, usually exhibited yaw rates of between 10 to 20 degrees per second, and from 16 to 20 seconds to roll from full left to full right turn.

This degree of maneuverability with respect to range of roll and turning radius was equalled, if not improved, upon incorporation of the rotary wrap flight control modification, with the result that the close-in flight characteristics appeared to be capable of keeping the glider overhead of the target/transmitter once station passage had been accomplished.

4. Landing Loads and Velocities

This report contains the ciné-theodolite data obtained from three different flights. The data show rate of descent and horizontal and vertical velocities. According to these data, the vertical velocities varied between 12 and 16 feet per second. There were no significant instances of damage resulting from the landing impact of an inflated glider.

5. Interpretation of Measured and Predicted Glider Performance

The flight test data obtained by ciné-theodolite tracking are shown to be in good agreement with the predicted values.

The predicted performance was based on the following:

1. Lift and drag per Figure 4.
2. Gross weight and altitude same as for comparable flight tests.

No instrumentation was installed on this system. Each wing was flown at 30 degrees angle of attack.

Glide performance was obtained from ciné-theodolite data as follows:

1. Rate of descent = $\frac{dh}{dt}$ = slope of altitude-vs-time curve.

2. The glide velocity obtained by ciné-theodolite data is a ground velocity exhibiting a variation in value throughout the flight due to vector addition of the airspeed and groundspeed of the glider. The true airspeed (average) was obtained by

$$V_{TAS} = \frac{V_{max} + V_{min}}{2}$$

   with maximum and minimum velocities evaluated within the glide range being investigated.

3. Flight path angle = $\gamma = \sin^{-1} \frac{h}{V}$.

4. Lift-to-drag ratio = $\frac{L}{D} = \frac{1}{\tan \gamma}$

NOTE:

1. CALIBRATED AIRSPEED ≈ EQUIVALENT AIRSPEED
2. WEIGHTS ARE TOTAL LAUNCH WEIGHT EXCEPT
   *( ) INDICATES PAYLOAD WEIGHT
3. FOR SINGLE ENGINE AIRCRAFT
4. MULTI-ENGINE (C-47) LIMITED TO 325(200) LBS
   AT 90 KNOTS CALIBRATED

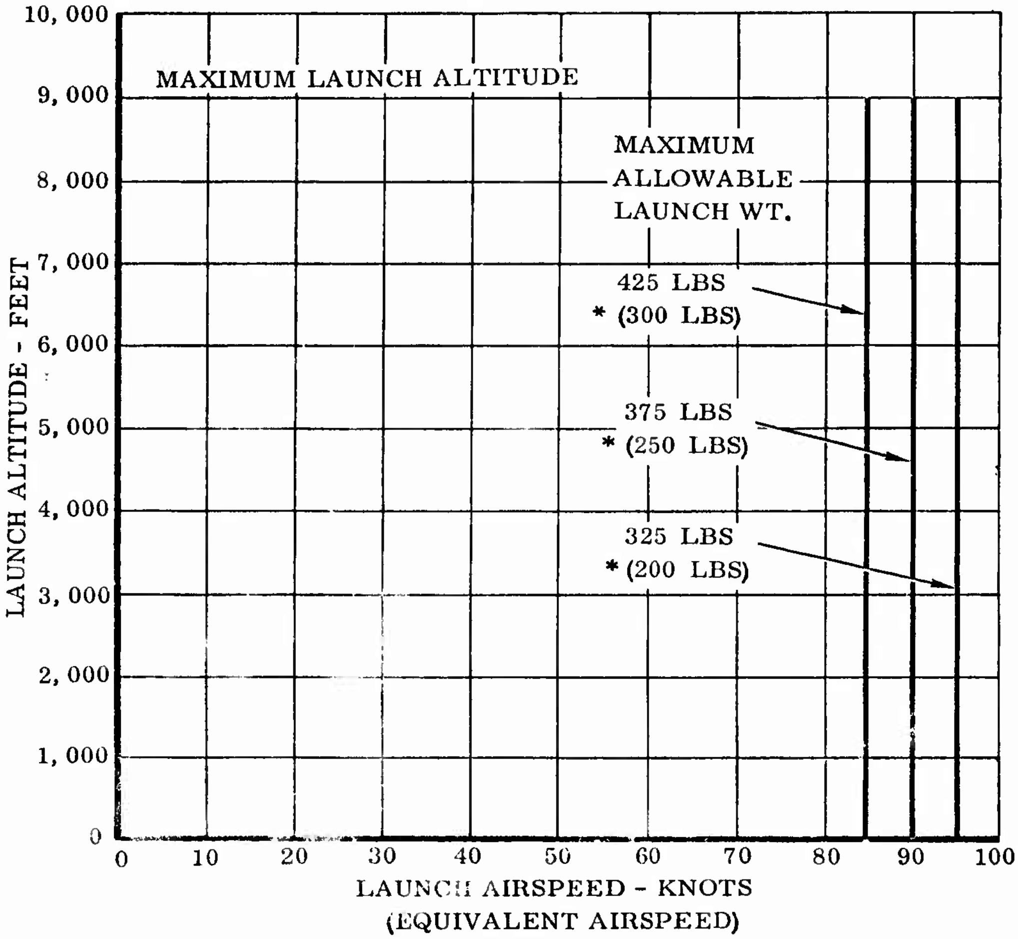


Figure 46 Launch Envelope

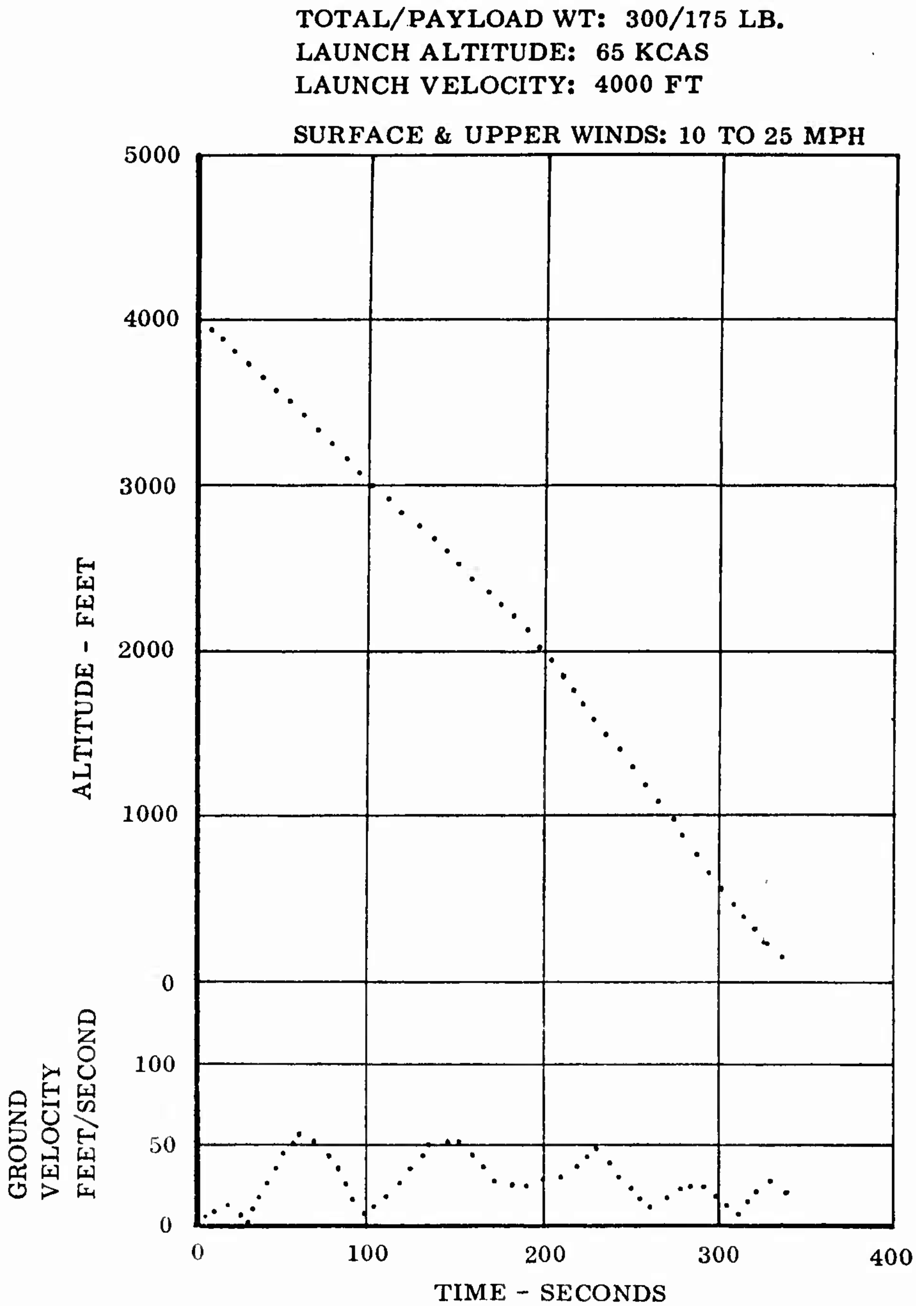


Figure 47 Flight History - Flight 52

CHART VII LONGITUDINAL VS. LATERAL DISPLACEMENT

NOTES:

1. NUMBERED CALL-OUTS ARE FLIGHT TIME IN SECONDS
2. ○ R/H TURN COMMAND SIGNAL INITIATED
3. ▲ R/H TURN COMMAND SIGNAL TERMINATED
4. □ L/H TURN COMMAND SIGNAL INITIATED
5. ◇ L/H TURN COMMAND SIGNAL TERMINATED
6. ● HOMING MODE INITIATED
7. ▼ HOMING MODE TERMINATED
8. SURFACE & UPPER WINDS NW - 10 TO 25 MPH
9. IMPACT: 1200 FT. SOUTH OF TARGET/TRANSMITTER
10. FLIGHT TIME: 348 SECONDS
11. ESTIMATED FLIGHT PATH AFTER CINE-THEODOLITE DATA EXPENDITURE

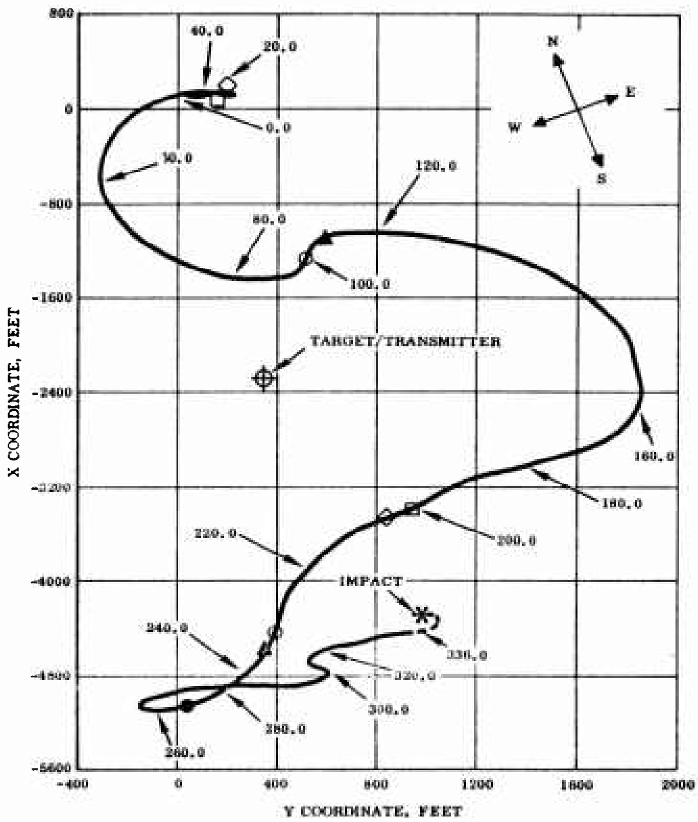


Figure 48 Flight Path History - Flight 52

TOTAL/PAYLOAD WT: 325/200 LB
LAUNCH ALTITUDE: 5000 FT
LAUNCH AIRSPEED: 65 KCAS

SURFACE & UPPER WINDS
20 TO 30 MPH

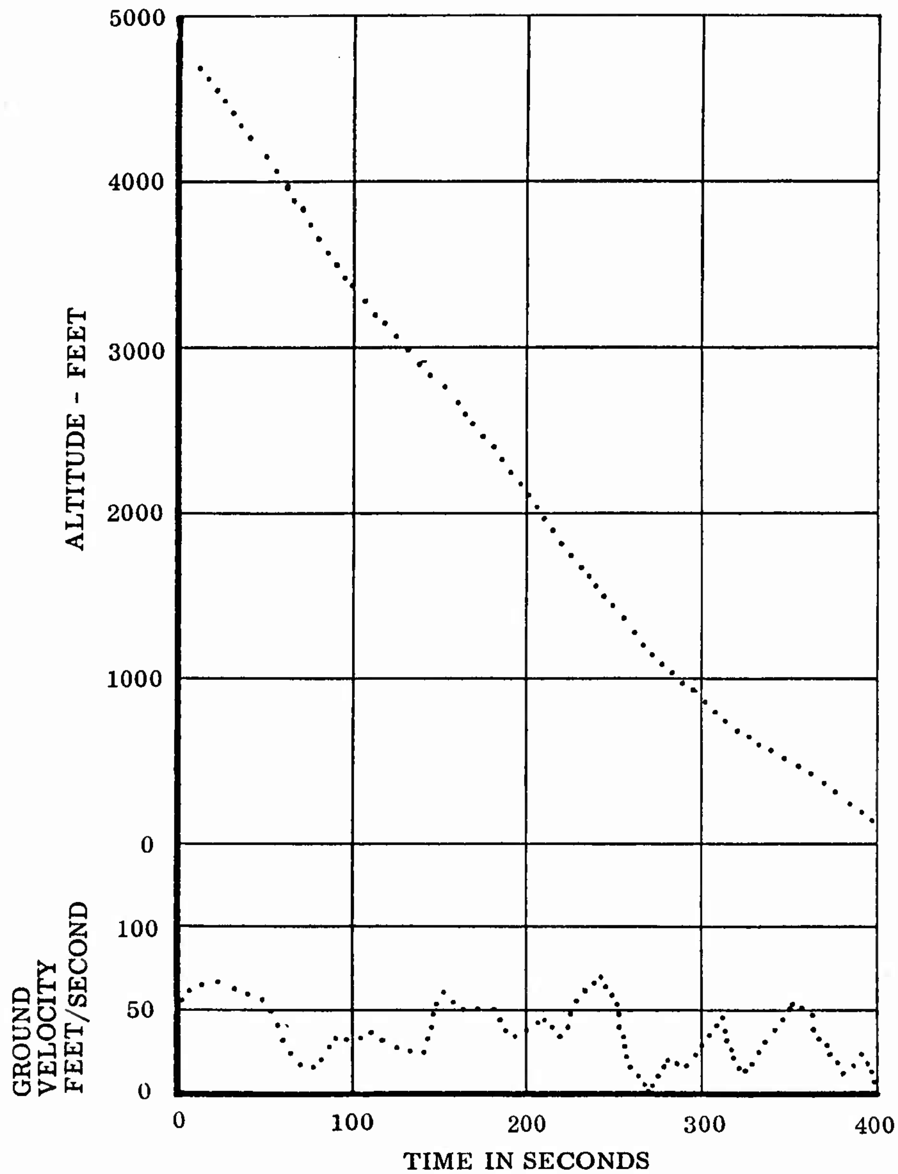


Figure 49 Flight History - Flight 77

CHART VII LONGITUDINAL VS. LATERAL DESPLACEMENT

NOTES:

1. NUMBERED CALL-OUTS ARE FLIGHT TIME IN SECONDS FROM LAUNCH
2. ○ R/H TURN COMMAND SIGNAL INITIATED
3. ▲ R/H TURN COMMAND SIGNAL TERMINATED
4. □ L/H TURN COMMAND SIGNAL INITIATED
5. ◇ L/H TURN COMMAND SIGNAL TERMINATED
6. ● HOMING MODE INITIATED
7. ▼ HOMING MODE TERMINATED
8. SURFACE & UPPER WINDS NORTHERLY - 20 TO 30 MPH
9. IMPACT: 250 FT. SW OF TARGET/TRANSMITTER
10. FLIGHT TIME: 408 SECONDS
11. ESTIMATED FLIGHT PATH AFTER CINE-THEODOLITE FILM EXPENDITURE

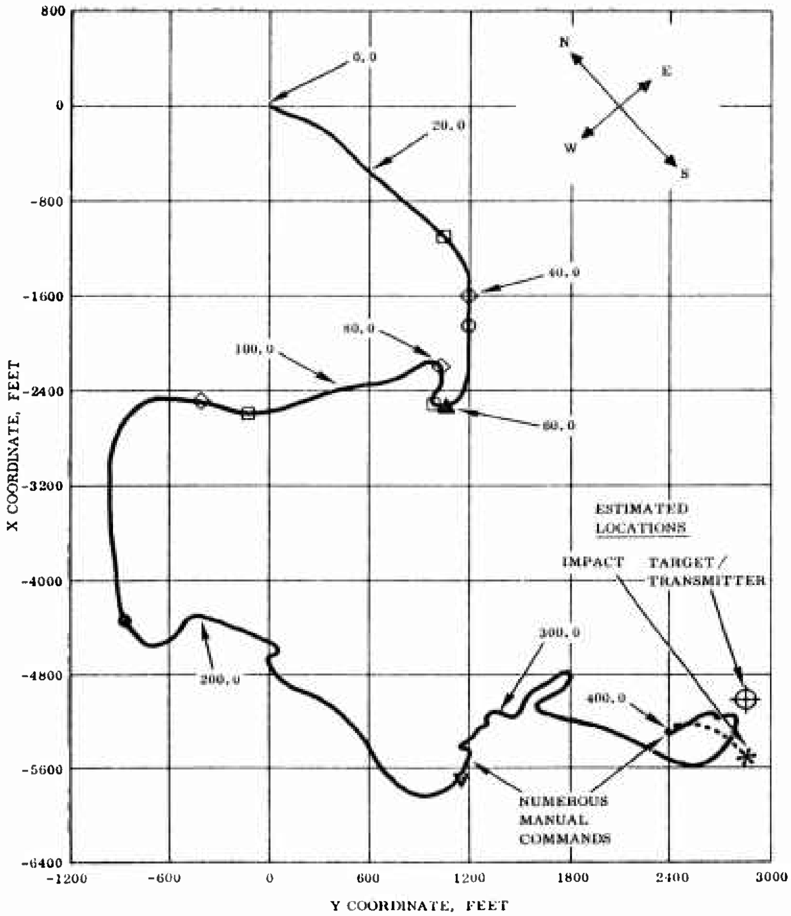


Figure 50 Flight Path History- Flight 77

TOTAL/PAYLOAD WT: 325/200 LB
LAUNCH ALTITUDE: 9000 FT
LAUNCH AIRSPEED: 65 KCAS

SURFACE & UPPER WINDS CALM

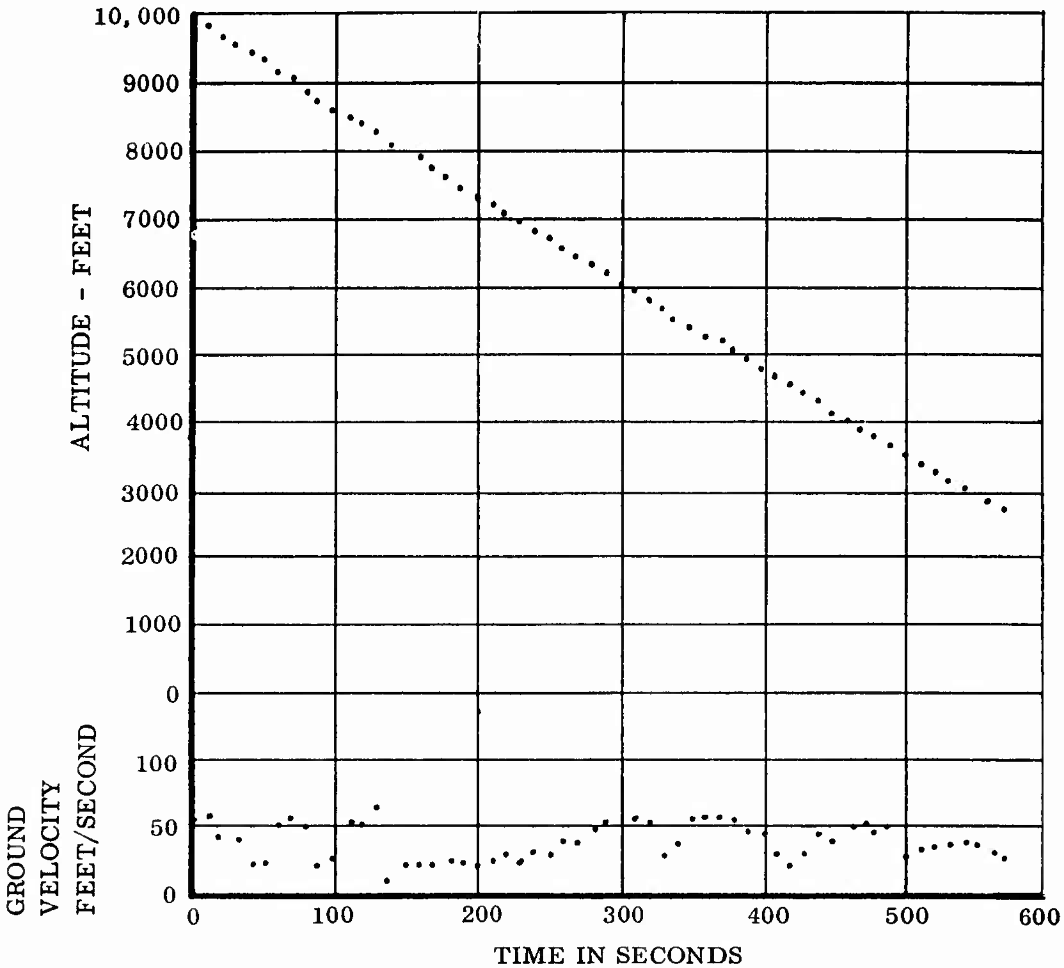


Figure 51 Flight History - Flight 84

CHART VII LONGITUDINAL VS LATERAL DISPLACEMENT

NOTES:

1. NUMBERED CALL-OUTS ARE FLIGHT TIME IN SECONDS
2. R/H TURN COMMAND SIGNAL INITIATED
3. R/H TURN COMMAND SIGNAL TERMINATED
4. L/H TURN COMMAND SIGNAL INITIATED
5. L/H TURN COMMAND SIGNAL TERMINATED
6. SURFACE & UPPER WINDS, CALM
7. IMPACT: 80 FT. SOUTH OF TARGET/TRANSMITTER
8. FLIGHT TIME: 694 SECONDS
9. ESTIMATED FLIGHT PATH AFTER CINE-THEODOLITE FILM EXPENDITURE
10. HOMING MODE INITIATED
11. HOMING MODE TERMINATED

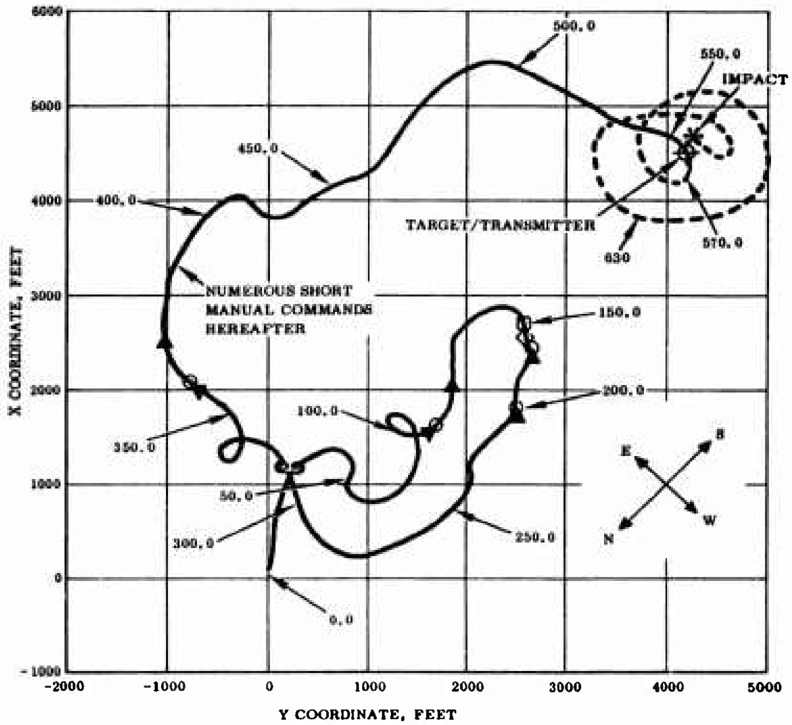


Figure 52 Flight Path History - Flight 84

TABLE 1

CONFIGURATION CHANGES PRIOR TO EACH FLIGHT TEST OPERATION

1. Basic. Launched from U-1A

2. Tied parachute release cutter pins together with safety wire. (Insure simultaneous opening of both fore and aft latches.)

3. Rotated quick-release latches 90° from normal position and tie latches closed with one loop of 1,000-pound line. (Simultaneous latch release, eliminate entanglement.)

4. No air bottle restrictor (evaluate removal).

5. Installed dummy antennas. Tied back on top of forward risers with 80-pound break cord. (Eliminate entanglement possibility.)

6. Installed restrictor. (Prevent leading edge tube kinking.) Stowed antennas below risers. (Prevent entanglement possibility.)

7. Same as 6.

8. Same as 6.

9. No restrictor. Drop altitude increased from 1,000 to 2,000 feet. (More time in flight.)

10. Same as 9.

11. Same as 9.

12. Same as 9.

13. Increased nose, 6 ft. 8 in. to 9 ft. 8 in., and decreased leading edge No. 2, 11 ft. 10 in. to 10 ft. 10 in., parachute line lengths only. Pack configuration "D". Nose folded under 12 inches; reefing cutter mounted on rear release latch instead of forward. (Reduce opening shock loads.)

TABLE I - Continued

14. Same as 12.

15. Same as 13.

16. Same as 13.

17. Same as 13.

18. Same as 13. Altitude 3,000 feet. (Increase flight duration.)

19. Increased total/payload weight: 330/220 pounds. (Structural build-up.) Altitude, 2,000 feet.

20. Same as 19.

21. Same as 19.

22. Reefing latches tied with closed loop instead of dead-ending line. (Attempt to eliminate single reefing cutter attach line failures.)

23. M2A1 reefing cutter used with separate double 1,000-pound line for each latch. "E" pack configuration. (Obtain simultaneous latch opening and also withstand opening shock loads.)

24. M2A1 reefing cutter rotated 90°. (Avoid powder burns on latches; also easier maintenance.) Launch speed 75 KCAS. (Structural build-up.) 4-second reefing cutter used. (Available stock.)

25. Increased total/payload weight: 380/250 pounds. Launch speed, 75 KCAS. (Structural build-up.)

26. Enlarged reefing cutter holes to 1/2-inch length, same width, to accept 3,000-pound strap folded double. Strap looped in figure-8 fashion and passed through cutter. Reduced total/payload weight: 330/200 pounds. (Structural build-up; prevent premature latch release due to line failure.)

TABLE 1 - Continued

27. Increased total/payload weight: 430/300 pounds. Launch speed, 65 KCAS. (Structural build-up.) Altitude, 1, 500 feet.

28. Rig = 34° by shortening aft glider lines 2-3/4 inches. (Evaluate.) Altitude, 4, 000 feet.

29. Rig = 30° by lengthening aft glider lines 2-3/4 inches. (Evaluate.) Increased launch speed: 75 KCAS. (Structural build-up.) Altitude, 2, 000 feet.

30. Reduced total/payload weight: 230/100 pounds, launch speed, 65 KCAS. 6-second wing cutter. Use 1, 000-pound nylon line as loop for quick-release latches. Double each riser travel for given traveler displacement by passing each riser over a roller on the traveller and dead ending the riser back near the entry slot on the control box. (Increase flight control response.) Altitude, 4, 000 feet.

31. Keel modification. Lowered keel, with nose line 4-1/2 inches shorter, air bottle line 11 inches shorter. (Reduce trailing edge flutter, increase flight control effectiveness.) Original one-to-one riser displacement.

32. Extended keel nose line 4-1/2 inches. Extended both aft risers by 2 inches. (Better wing aerodynamic shape.) Increase total/payload weight to 330/200 pounds. (Structural build-up.)

33. Reduced total/payload weight: 230/100 pounds. Altitude, 2, 000 feet.

34. Installed high-capacity air bottle: 205 cu. in. (Obtain positive wing inflation.) 6-second wing reefing cutter. 1, 000-pound line in reefing cutter latches: "D" packing configuration. (Eliminate hang-up of 3, 000-pound nylon strap.) Initiated single control line of aft leading edge lines to traveler, replacing aft riser strap control technique. (Evaluate.)

35. Increased air bottle pressure from 2, 500 to 3, 000 psig. (To obtain 9 psig in tubes.) Reverse field connections on servo. (Aft leading edge

TABLE I - Continued

flight control modification provides aileron effect instead of c. g. shift as with aft riser flight control.)

36. Shortened the leading edge control lines by 3 inches. (To increase the resisting force in each line for more positive "aileron" response.) Increased aft riser length by 2 inches. Increased total/payload weight to 300/175 pounds. Altitude 3, 000 feet.

37. Increased air bottle pressure to 3. 400 psig. (For 9 psig tube pressure.) Low-capacity bottle: 4, 000 psig.

38. Same as 37.

39. Same as 37.

40. Two 1, 000-pound nylon loops dead-ended to latch. (Evaluate.)

41. Same as 39.

42. Large-capacity air bottle: 3, 400 psig. All wings have lowered keel, control system, and five gusset modifications completed for standard wing. Use 4-second wing reefing cutter. (Availability.)

43. Rigged M2A1 cutter to rigging. (Safety to ground personnel.)

44. Same as 43.

45. M2A1 safety wire discontinued. (Method of safety wire used was ineffective and caused entanglements. Offset launches to be used.)

46. Same as 45.

47. Same as 45.

48. Added 40 inches of doubler to underside of wing 103 leading edge near No. 1 gusset. (Prevent glider line burns and subsequent pressure loss.)

TABLE I - Continued

49. Lay on three layers of green tape around both leading edge tailcones and wing. (Prevent line pickup from slipping in between tailcone and underside of wing.) Altitude, 4,000 feet. "F" pack configuration.

50. Same as 49.

51. "G" pack configuration: Separate risers, parachute only. See Table 5 for 5-foot-shorter parachute line lengths. (Investigate opening shock loads on a simulated "control box latch modification" prior to factory incorporation.) Altitude, 2,000 feet.

52. Same as 49.

53. Same as 51. Increased total/payload weight to 425/300 pounds. Increased airspeed from 65 to 75 KCAS. (Structural build-up.) Altitude 2,000 feet.

54. Same as 49.

55. Same as 49.

56. Same as 53. Increased airspeed from 75 to 85 KCAS. (Structural build-up.) Altitude, 2,000 feet.

57. Same as 49.

58. Same as 53. Increased airspeed from 85 to 95 KCAS. (Structural build-up.) Altitude, 2,000 feet.

59. Same as 49.

60. Same as 58. Decreased total/payload weight: 335/200 pounds. (Structural build-up.) Altitude, 2,000 feet. Replace all parachute lines. (Lines stretched.)

61. "H" pack configuration. Double line stowage under gussets. (Prevent line "shake-out" from opening shock.) Triple control; L5 and R5 glider lines lengthened from 19 feet 10 inches to 20 feet 4 inches. (Increase flight control response.) Altitude, 4,000 feet.

TABLE I - Continued

62. Same as 61.

63. Same as 58. Increased total/payload weight to 375/250 pounds. (Structural build-up.) Altitude, 2,000 feet.

64. Same as 49.

65. Same as 61.

66. "I" pack configuration. Same as "F" pack except double line stowage and shorter parachute lines mounted to control box latches, eliminating risers during the chute period. Double or triple control is optional. (Triple used on this flight.) See Table 6 for line lengths. (Separation of forward and aft parachute lines, and reduction of opening shock loads.) Altitude, 4,000 feet. 6-second wing cutter.

67. Same as 49. 6-second wing reefing cutter.

68. "F" pack configuration. Shortened double control line from 19 feet 9 inches to 19 feet 6 inches - standard.

69. "G" pack configuration. Altitude increased to 9,000 feet, airspeed to 95 KCAS, total/payload weight to 325/200 pounds. (Structural build-up.)

70. Increased total/payload weight to 425/300 pounds. Launch airspeed, 85 KCAS. Altitude, 9,000 feet. (Structural build-up.) Weights bolted to plywood plank. (Prevent weight shift.)

71. "I" pack configuration. Double control. L5 and R5 control line length = 19 feet 6 inches. Double glider line stowage at gussets. Mechanical latches. Total/payload weight: 325/200 pounds. Launch airspeed, 90 KCAS. Altitude, 4,000 feet. (Structural build-up and deployment to glider.)

TABLE I - Continued

72. Same as 71. Launch airspeed, 95 KCAS. Altitude, 1,200 feet. (Structural build-up and deployment to glider.) L2a and R2a glider line stowage revision. (Prevent pickup of line.)

73. Control box 103 modified for simulated parachute line latch installation. (Evaluate "G" pack configuration with Wing 101 in actual "I" pack configuration.)

74. Same as 71. Launch airspeed, 95 KCAS. Altitude, 9,000 feet. (Structural build-up at altitude.) 6-second wing reefing cutter.

75. "F" pack configuration. Low-capacity air bottle, 4,000 psig. Double control. (Demonstrate homing.) Altitude, 3,000 feet. Launch airspeed, 65 KCAS.

76. "I" pack configuration. Total/payload weight: 325/200 pounds. Altitude, 5,000 feet. High-capacity air bottle, 3,000 psig. (Demonstrate manual control and homing.)

77. Same as 76. Air bottle, 3,200 psig. (Attain 9-psig tube pressure.) All four antennas to be unscrewed from spring mounts instead of release from set screw. (Set screws to be permanently placed to prevent antenna loss at launch.)

78. Same as 77. Triple control. (Investigate homing response.)

79. Same as 77. Altitude, 7,000 feet.

80. Same as 75. Double control. Altitude, 6,000 feet.

81. "I" pack configuration. Total/payload weight: 325/200 pounds. Launch airspeed, 65 KCAS. Altitude, 6,000 feet. Flight control system modified in homing mode so that traveler drove toward neutral 7° before line to homer was crossed "null modification". (Prevent divergent flight path in homing mode.)

TABLE I - Continued

82. Null modification removed. (Much greater lead time required to provide a convergent flight path in the homing mode with present traveler rate.) Altitude, 6,000 feet.

83. Same as 82. Altitude, 7,000 feet. (Evaluate manual control and homing.)

84. Same as 82. Altitude, 9,000 feet. (Evaluate manual control and homing.)

85. Same as 82. Altitude, 6,500 feet. (Evaluate manual control and homing.)

86. Triple control. Control line length 20 feet 2 inches. Restricted traveler displacement. (Evaluate response to homing mode with reduced rate of turn.) Altitude, 6,000 feet.

87. Same as 85. Double control. (Triple control discontinued; forces on traveler too high.) Altitude, 4,000 feet. (Evaluate manual control and homing.)

88. Same as 87. (Evaluate manual control and homing.)

89. Same as 87. Altitude, 9,000 feet. (Evaluate manual control and homing.)

90. Decreased total/payload weight: 275/150 pounds. Altitude, 6,000 feet. (Demonstrate manual control to impact at target.)

91. Same as 90. (Demonstrate manual control to impact at target.)

92. "I" pack configuration. Total/payload weight: 385/350 pounds, airspeed, 95 KCAS, altitude, 5,000 feet, double control, rigged for α = 30°, air bottle pressure of 3,200 psig, offset 2 miles from the target, utilizing manual control.) Reefing cutters at 1.5 seconds (pneumatic) and 6 seconds (wing).

TABLE I - Continued

93. Same as 92.

94. Same as 92.

95. Increased spring tension to high-pressure pin release on air bottle. (Override pin "hang-up" friction.)

96. Same as 95.

97. Same as 95.

98. Same as 95.

99. Same as 95.

100. Nylon packet installed on bottle fill collar. (Prevent air-bottle high-pressure-pin lanyard breakage.)

101. Same as 100.

102. Same as 100.

103. Same as 100.

104. Same as 100.

105. Same as 100.

106. Reduce launch airspeed to 90 KCAS. Reduce total/payload weight to 325/200 pounds. (Evaluate.)

107. Same as 106.

108. "J" pack configuration: Lengthened both No. 2 keel glider lines by 3 inches. (Eliminate crease in wing shape.) Reduce total/payload weight: 300/175 pounds; launch airspeed, 65 KCAS. (Demonstrate homing only.)

TABLE I - Continued

109. Same as 108.

110. Launch airspeed to 95 KCAS. (Continue structural program.) Launch from CV-2A "Caribou". Increase total/payload weight to 375/250 pounds. (Evaluate.)

111. Launch airspeed, 90 KCAS. Launch from CV-2A. Decrease total/payload weight to 325/200 pounds. (Evaluate.) Decrease air-bottle pressure to 2900 psig. (To obtain 7.5 psig tube pressure.)

112. Extend both No. 2 keel glider lines by another 2 inches. (Crease still in wing.)

113. Same as 112.

114. Same as 112.

115. Same as 112.

116. Same as 112.

117. Same as 112.

118. Replace normal traveler method of control line displacement with "Rotary Wrap" method of control line displacement. (Achieve better compatibility between glider yaw rate and control line displacement rate.)

119. Use the double control system of control line displacement. (Other control box not yet modified.) Double parachute lines. (Decrease possibility of line breakage due to launch.)

120. Utilize "Rotary Wrap" control system. (All airborne control boxes now modified.) Increase total/payload weight to 375/200 pounds. (Evaluate.)

TABLE I - Continued

121. Increase total/payload weight to 360/230 pounds. (Evaluate.)

122. Same as 121.

123. Same as 121.

124. Same as 121.

125. Same as 121.

126. Same as 121.

127. Reduce launch airspeed to 75 KCAS. Reduce total/payload weight to 330/200. Utilize 11-foot sleeve with 6-foot static line. Shorten both No. 2 keel lines 6 inches. (Re-initiate structural investigation from known configuration and launch conditions.) Removed spring clips from aft latch on control box. (Clips no longer needed with rotary wrap control method.) Single parachute lines. (Two lines appeared to create additional line pickup possibilities.)

128. Increase launch airspeed to 95 KCAS. (Continue program.)

129. Same as 128. Altitude, 3,000 feet.

130. Control system set for ± 9 inches for homing and ± 17 inches for manual control for control line displacement. Null zone set for 6.2° (±3.1°) edge to edge. (Obtain convergent glider oscillations in the homing mode or fast response with minimum lead time in manual control.) Altitude, 4,000 feet.

131. Same as 130. Altitude, 5,000 feet.

132. Reduce launch airspeed to 90 KCAS. Lengthen static line to 11 feet but retain the static line break point at 6 feet of PDG vehicle motion. (C-47 launch technique for a total/payload weight of 330/200 pounds.)

TABLE I - Continued

133. Same as 132. Painted wing - Power off launch from C-47.

134. Same as 132. Partial power launch from C-47.

135. Same as 132. Partial power launch from C-47.

136. Same as 132. Partial power launch from C-47.

137. "L" pack configuration: Investigation of elastic loop line stowage method, to preclude line pickup. Launch airspeed to 65 KCAS. 6-foot static line. (C-47 use discontinued for this test program.)

138. Launch airspeed, 65 KCAS. First launch from UH-1 helicopter, configuration "K".

139. Same as 137.

TABLE 2
DROP TEST CHRONOLOGY

FTO No.	Total/Payload Weight (Pounds)	Drop Alt. (Ft.)	Drop A. S. KCAS	Launch Aircraft	Pack Conf.	Wing (2) Cutter Times (Seconds)	Air Bot. Pres. (PSIG)	Glider Obtained	Manual Control Response	Homing Mode Response
1	225/100	1000	65	U-1A	A	6	4000			
2	225/100	1000	65	U-1A	A	6	4000			
3	225/100	1000	65	U-1A	C	6	4000			
4	225/100	1000	65	U-1A	C	6	4000	Yes		
5	225/100	1000	65	U-1A	C	6	4000	Yes		
6	225/100	1000	65	U-1A	C	6	4000			
7	225/100	1000	65	U-1A	C	6	4000	Yes		
8	225/100	1000	65	U-1A	C	6	4000			
9	225/100	2000	65	U-1A	C	6	4000	Yes		
10	225/100	2000	65	U-1A	C	6	4000	Yes	Cont. R. T.	
11	225/100	2000	65	U-1A	C	6	4000		Input Rec'd	
12	225/100	2000	65	U-1A	C	6	4000		Input Rec'd	
13	225/100	2000	65	U-1A	D	6	4000	Yes	Very Slight	
14	225/100	2000	65	U-1A	D	6	4000		Input Rec'd	
15	225/100	2000	65	U-1A	D	6	4000	Yes		
16	225/100	2000	65	U-1A	D	6	4000	Yes	Input Rec'd	
17	225/100	2000	65	U-1A	D	6	4000	Yes	Input Rec'd	
18	225/100	3000	65	U-1A	D	6	4000	Yes	Possibly	
19	325/100	2000	65	U-1A	D	6	4000	Yes	L. T. only	
20	325/200	2000	65	U-1A	D	6	4000	Yes	R. T. only	
21	325/200	2000	75	U-1A	D	6	4000		(3)	
22	325/200	2000	65	U-1A	D	6	4000	Yes	Input Rec'd	
23	325/200	2000	65	U-1A	E	6	4000	Yes	L. T. only	
24	325/200	75	75	U-1A	E	4	4000			

FTO No.	Total/Payload Weight (Pounds)	Drop Alt. (Ft.)	Drop A. S. KCAS	Launch Aircraft	Pack Conf.	Wing (2) Cutter Times (Seconds)	Air Bot. Pres. (PSIG)	Glider Obtained	Manual Control Response	Homing Mode Response
25	325/250	2000	75	U-1A	E	4	4000		(3)	
26	325/200	2000	65	U-1A	E	4	4000	Yes		
27	425/300	1500	65	U-1A	E	4	4000			
28	425/300	4000	65	U-1A	E	4	4000	Yes	No L. T.	
29	425/300	2000	75	U-1A	E	4	4000			
30	225/100	4000	65	U-1A	E	6	4000	Yes	No	
31	225/100	4000	65	U-1A	E	4	4000	Yes	Single R. T.	
32	325/200	4000	65	U-1A	E	4	4000			
33	225/100	2000	65	U-1A	E	4	4000			
34	225/100	2000	65	U-1A	D	6	4000	Yes	Yes	
35	225/100	2000	65	U-1A	D	6	3000	Yes	No	
36	300/175	3000	65	U-1A	D	6	4000	Yes	Yes	
37	300/175	3000	65	U-1A	D	6	3400		8 sec. L. T.	(3)
38	300/175	3000	65	U-1A	D	6	4000	Yes	Yes	L. T. only
39	300/175	3000	65	U-1A	D	6	4000			
40	300/175	3000	65	U-1A	F	6	4000			
41	300/175	3000	65	U-1A	D	6	4000		(4)	
42	300/175	3000	65	U-1A	F	4	3400	Yes	No R. T.	
43	300/175	4000	65	U-1A	F	4	3400	Yes	R. T. ok	
44	300/175	4000	65	U-1A	F	4	3400			
45	300/175	4000	65	U-1A	F	4	4000			
46	300/175	4000	65	U-1A	F	4	3400			
47	300/175	4000	65	U-6A	F	4	3400			
48	300/175	4000	65	U-6A	F	4	3400		(4)	
49	300/175	4000	65	U-6A	F	4	3400	Yes	L. T. only	
50	300/175	4000	65	U-6A	F	4	3400	Yes	R. T. only	No
51	300/175	2000	65	U-6A	G	(1)				
52	300/175	4000	65	U-6A	F	4	3400		Good	± 30° Osc. (6)

FTO. No.	Total/Payload Weight (Pounds)	Drop Alt. (Ft.)	Drop A. S. KCAS	Launch Aircraft	Pack Conf.	Wing (2) Cutter Times (Seconds)	Air Bot. Press. (PSIG)	Glider Obtained	Manual Control Response	Homing Mode Response
53	425/300	2000	75	U-6A	G	(1)		-	-	-
54	300/175	4000	65	F	4	3400	Yes	-	-	-
55	300/175	4000	65	U-6A	F	4	3400	Yes	Yes	No
56	425/300	2000	85	U-6A	G	(1)	-	-	-	-
57	300/175	4000	65	U-6A	F	4	3400	Yes	Yes	No
58	425/300	2000	95	U-6A	G	(1)	-	-	-	-
59	300/175	4000	65	U-6A	F	4	3400	-	(3)	-
60	325/200	2000	95	U-1A	G	(1)	-	-	-	-
61	300/175	4000	65	U-1A	H	4	3400	Yes	R. T. only	-
62	300/175	4000	65	U-1A	H	4	3400	Yes	R. T. only	No
63	375/250	2000	95	U-1A	G	(1)	-	-	-	-
64	300/175	4000	65	U-1A	F	4	3400	-	-	-
65	300/175	4000	65	U-1A	H	4	3400	Yes	Yes	Erratic
66	425/300	4000	85	U-1A	I	6	3400	-	-	-
67	300/175	4000	65	U-1A	F	6	3400	Yes	Erratic	No
68	300/175	4000	65	U-1A	F	6	3400	Yes	Yes	-
69	325/200	9000	95	U-1A	G	(1)	-	-	-	-
70	425/300	9000	85	U-1A	G	(1)	-	-	-	-
71	325/200	4000	90	U-6A	I	6	3400	-	-	-
72	325/200	1200	95	U-1A	I	6	3400	Yes	Yes	No
73	325/200	1100	95	U-1A	I	(1)	-	-	-	-
74	325/200	9000	95	U-1A	I	6	3000	-	-	-
75	325/200	3000	65	U-1A	F	6	4000			
76	325/200	5000	65	U-6A	I	6	3000	Yes	Yes	-
77	325/200	5000	65	U-6A	I	6	3200	Yes	Yes	-
78	325/200	5000	65	U-1A	I	6	3200	Yes	Very slow	No

FTO No.	Total/Payload Weight (Pounds)	Drop Alt. (Ft.)	Drop A. S. KCAS	Launch Aircraft	Pack Conf.	Wing (2) Cutter Times (Seconds)	Air Bot. Pres. (PSIG)	Glider Obtained	Manual Control Response	Homing Mode Response	Impact From Target - F
79	325/200	7000	65	U-1A	I	6	3200	Yes	Yes	-	-
80	325/200	6000	65	U-1A	F	6	4000	Yes	No	No	-
81	325/200	6000	65	U-1A	I	6	3200	Yes	L. T. very slow	No	200
82	325/200	6000	65	U-1A	I	6	3200	-	(3)	-	4000
83	325/200	7000	65	U-6A	I	6	3200	Yes	R. T. only	L. T. only	2000
84	325/200	9000	65	U-6A	I	6	3200	Yes	Yes	(5)	80
85	325/200	6500	65	U-1A	I	6	3200	Yes	Yes	(5)	250
86	325/200	6000	65	U-1A	I	6	3200	Yes	Yes	-	1000
87	325/200	4000	65	U-1A	I	6	3200	Yes	Yes	-	25
88	325/200	4000	65	U-1A	I	6	3200	-	-	-	5000
89	325/200	9000	65	U-1A	I	6	3200	Yes	Very slow	No	2000
90	275/150	6000	65	U-6A	I	6	3200	Yes	Yes	-	60
91	275/150	6000	65	U-6A	I	6	3200	Yes	Yes	-	10
92	375/250	5000	95	U-6A	I	6	3200	-	-	-	10000
93	375/250	5000	95	U-6A	I	6	3200	Yes	-	No	300
94	375/250	5000	95	U-6A	I	6	3200	Yes	-	No	60
95	375/250	5000	95	U-6A	I	6	3200	Yes	Irregular Response	-	1900
96	375/250	5000	95	U-6A	I	6	3200	-	N. A.	-	10000
97	375/250	5000	95	U-6A	I	6	3200	-	N. A.	-	10000
98	375/250	5000	95	U-6A	I	6	3200	-	(3)	-	10000
99	375/250	5000	95	U-1A	I	6	3200	-	(3)	-	10000
100	375/250	5000	95	U-1A	I	6	3200	-	(3)	-	10000
101	375/250	5000	95	U-6A	I	6	3200	-	(3)	-	5000
102	375/250	5000	95	U-1A	I	6	3200	-	-	-	10000
103	375/250	5000	95	U-1A	I	6	3200	Yes	Fair, L. T., No R. T.	-	2000

FTO. No.	Total/Payload Weight (Pounds)	Drop Alt. (Ft.)	Drop A. S. KCAS	Launch Aircraft	Pack Conf.	Wing (2) Cutter Times (Seconds)	Air Bot. Pres. (PSIG)	Glider Obtained	Manual Control Response	Homing Mode Response	Impact From Target-Ft.
104	375/250	5000	95	U-6A	I	6	3200	Yes	Sluggish Response		300
105	375/250	5000	95	AC-1	I	6	3200	Yes	Yes		25
106	325/200	5000	90	U-1A	I	6	3200				10000
107	325/200	5000	90	U-6A	I	6	2900				10000
108	300/175	5000	65	U-1A	J	6	2900		(3)		10000
109	300/175	5000	65	U-1A	J	6	2900	Yes	Slow		500
110	375/250	5000	95	AC-1	J	6	3200	Yes	L. H. Turns only		1000
111	325/200	5000	90	U-1A	J	6	2900				10000
112	325/200	5000	90	U-1[illegible]	J	6	2900	Yes	L. T. & Center only		1500
113	325/200	5000	90	U-1A	J	6	2900	Yes	Good L. T., fair R. T.		120
114	325/200	5000	90	AC-1	J	6	2900	Yes	L. T. Spiral R. T. ineffective		2000
115	325/200	5000	90	U-6A	J	6	2900				10000
116	325/200	5000	90	U-1A	J	6	2900	Yes	Poor R. T. L. T. only		2000
117	325/200	5000	90	U-1A	J	6	2900	Yes	Poor R. T. Good L. T.		4000
118	325/200	5000	90	U-6A	J	6	2900	Yes	Good		27
119	325/200	5000	90	U-6A	J	6	2900	Yes	Poor R. T. Good L. T.		15000
120	375/350	5000	90	U-1A	J	6	2900				5000
121	355/230	5000	90	U-1A	J	6	2900	Yes	No response		5000
122	355/230	5000	90	U-1A	J	6	2900				10000
123	355/330	5000	90	U-1A	J	6	2900	Yes	No response		10000

FTO No.	Total/Payload Weight (Pounds)	Drop Alt. (Ft.)	Drop A. S. KCAS	Launch Aircraft	Pack Conf.	Wing (2) Cutter Times (Seconds)	Air Bot. Pres. (PSIG)	Glider Obtained	Manual Control Response	Homing Mode Response	Impact From Target-Ft.
124	355/230	5000	90	U-1A	J	6	2900				20000
125	355/230	5000	90	U-1A	J	6	2900				500
126	355/230	5000	90	U-1A	J	6	2900				1000
127	325/200	5000	75	U-6A	I	6	2900	Yes	Excellent		50
128	325/200	5000	95	U-6A	I	6	2900	Yes	Good		95
129	325/200	3000	95	U-1A	I	6	2900				3000
130	325/200	4000	95	U-1A	I	6	2900	Yes	Good L. T.	(6)	600
									Fair R. T.		
131	325/200	5000	95	U-6A	I	6	2900	Yes	Good L. T.		335
									Poor R. T.	L. T. only	
132	325/200	5000	90	C-47	I	6	2900	Yes	Fast L. T.	Good	250
									Slow R. T.		
133	325/200	4500	90	C-47	K	6	2900	Yes			7500
134	325/200	5000	90	C-47	I	6	2900				5000
135	325/200	5000	90	C-47	I	6	2900	Yes	Fast L. T.		400
									Slow R. T.	Good	
136	325/200	5000	90	C-47	J	6	2900	Yes	Good	(6)	420
137	325/200	5000	90	U-6A	L	6	2900	Yes		Erratic	3000
138	325/200	5000	90	UH-1	K	6	2900	Yes	Good	(6)	185
139	325/200	5000	90	U-1A	L	6	2900	Yes	L. T. only		175

Note:

(1) No cutters, parachute mode only.

(2) All parachute cutters were set for 1.5 seconds.

(3) Traveler displacement noted upon postflight inspection in response to manual control command inputs.

(4) No traveler displacement noted upon postflight inspection in response to manual control command inputs.

(5) Divergent home-seeking oscillations in yaw.

(6) Transmitter remained in homing mode until impact.

TABLE 3
PACK METHOD CONFIGURATION

	13-gusset wing	16-gusset wing	Restrictor	Low-capacity bottle	High-capacity bottle	Single parachute latch	Double parachute latch	Control box mech. latch	1, 000-2, 000 lb. loop in latch	3, 000 lb. loop in latch	Aft riser control	Double control	Triple control	Rotary wrap	1. 5 - 4 sec. cutters	1. 5 - 6 sec. cutters	3-ft. longer para nose line	5-ft. shorter para lines (1)	4. 5-ft. shorter para lines(2)	"W" sleeve pack	Lower keel mod.	Dbl. line gusset stowage	Control box glider ln. stow.	Lengthened No. 2 keel lines	Painted wing	Individual loop line stowage
A	X		X	X		X			X		X					X										
C	X		X	X		X			X		X					X										
D	X	X		X	X	X	X		X		X					X	X				X					
E	X	X		X			X			X	X				X	X	X				X					
F		X			X		X		X			X	X		X	X	X				X					
G	X				X												X	X		X	X					
H		X			X		X		X				X		X		X				X	X				
I		X			X			X				X	X	X	X	X	X		X	X	X	X	X			
J		X			X			X				X		X		X	X		X	X	X	X	X	X		
K		X			X			X						X		X	X		X	X	X	X	X	X	X	
L		X			X			X						X		X	X		X	X	X	X	X	X		X

NOTE: (1) Simulated spread risers
(2) Risers not used during parachute mode

TABLE 4

SHROUD LINE DESCRIPTION

Glider Line No.	Line Description
N1	Nose Line
L1	Left Leading Edge Line No. 1
R1	Right Leading Edge Line No. 1
K1	Keel Line No. 1
L2F	Left Leading Edge Line No. 2 Forward
R2F	Right Leading Edge Line No. 2 Forward
K2F	Keel Line No. 2 Forward
L2A	Left Leading Edge Line No. 2 Aft
R2A	Right Leading Edge Line No. 2 Aft
K2A	Keel Line No. 2 Aft
L3	Left Leading Edge Line No. 3
R3	Right Leading Edge Line No. 3
K3	Keel Line No. 3
L4	Left Leading Edge Line No. 4
R4	Right Leading Edge Line No. 4
K4	Keel Line No. 4
L5	Left Leading Edge Line No. 5
R5	Right Leading Edge Line No. 5
K5	Keel Line No. 5

Parachute Line No.	Line Description
Nose	Nose Parachute Line
L2F	Left Leading Edge No. 2 Parachute Line
R2F	Right Leading Edge No. 2 Parachute Line
L5 (L4)	Left Leading Edge No. 5 (4) Parachute Line
R5 (R4)	Right Leading Edge No. 5 (4) Parachute Line
K5 (K4)	Keel No. 5 (4) Parachute Line

Note: ( ) represents 13-gusset wing.
*See Figure 14 Suspension Line Nomenclature & Location

TABLE 5

LINE LENGTHS FOR THIRTEEN-GUSSET WINGS

PACK CONFIGURATION

	(Original)		(Modifications)	
	A, C		D	G
Line*	Glider	Parachute	Parachute	Parachute
N1	20'9"	6'0"	9'0"	4'8"
L1 & R1	17'11"			
L2F & R2F	15'10"	11'6"	10'6"	5'10"
L2A & R2A	16'3"			
L3 & R3	15'2"			
L4 & R4	16'2"	6' 5.5"	6'5.5"	1'0"
K1	16'5"			
K2F	14'2"			
K2A	14'5"			
K3	13'6"			
K4	13'11"	11'0"	11'0"	5'0"

*See Figure 14 for description of suspension lines.

NOTE: The letter "B" was not used in the designation of packing methods during the PDG flight test program.

TABLE 6

LINE LENGTHS FOR SIXTEEN-GUSSET WINGS

PACK CONFIGURATION

	(Original)		(Modifications)					
	D		D, E, F, H		I, K		J, L	
Line*	Glider	Para	"D" Keel	"D" Para	Glider	Para	Glider	Para
N1	20'0"	6'0"	20'0"	9'8"	20'0"	5'2"	20'0"	5'2"
L1 & R1	16'11"		16'11"		16'11"		16'11"	
L2F & R2F	14'11"	11' 6"	14'11"	10'10"	14'11"	6'4"	14'11"	6'4"
L2A & R2A	16'5"		16'5"		16'5"		16'5"	
L3 & R3	15'2"		15'2"		15'2"		15'2"	
L4 & R4	14'8"		14'8"		14'8"		14'8"	
L5 & R5	14'11"	6'0"	14'11"	6'0"	19'6"	1'6"	19'6"	1'6"
K1	16'8"		16'8"		16'8"		16'8"	
K2F	14'8"		14'1.2"		14'1.2"		14'7.2"	
K2A	16'0"		15'4.5"		15'4.5"		15'10.5"	
K3	14'7"		13'10.5"		13'10.5"		13'10.5"	
K4	13'11"		13'1"		13'1"		13'1"	
K5	13'11"	10'0"	13'0"	10'0"	13'0"	5'6"	13'0"	5'6"

*See Figure 14 for description of suspension lines.

TABLE 7

DROP TEST PROBLEM AREA CHRONOLOGY

FTO	Pack Config.	Air Bottle	Nose Tuck	Line Entanglement	Line Failure	Premature Wing	Riser Twist	Riser Failure	Gusset Failure	Air Loss	Reefing Cutter	Remote Control	Homing	Late Wing	Flt. Control Sys.	Broken Antenna	Line Lengths
1	A			X													
2	A		X														
3	C		X	X													
4	C																
5	C																
6	C		X	X													
7	C																
8	C		X	X													
9	C																
10	C																
11	C		X	X													
12	C			X													
13	D																
14	D	X															
15	D																
16	D																
17	D																
18	D																
19	D											X					
20	D											X					
21	D										X						
22	D																
23	D									X							
24	D	X									X						
25	D										X						
26	E											X	X				
27	E			X													
28	E											X		X			
29	E							X									
30	E											X			X		
31	E			X													
32	E										X	X					
33	E										X						
34	D											ok					
35	D						X					X					
36	D											ok					
37	D			X								ok					
38	D											ok	X				
39	D			X													
40	F		X	X													
41	D			X								X					
42	F											X	X				
43	F									X		ok					

FTO	Pack Config.	Air Bottle	Nose Tuck	Line Entanglement	Line Failure	Premature Wing	RiserTwist	Riser Failure	Gusset Failure	Air Loss	Reefing Cutter	Remote Control	Homing	LateWing	Flt. Control Sys.	Broken Antenna	Line Lengths
44	F										X						
45	F									X							
46	F			X													
47	F		X														
48	F			X								X					
49	F									X		X					
50	F											X					
51	G																
52	F											ok	ok				
53	G																
54	F			X													
55	F											ok	X				
56	G																
57	F											ok	X				
58	G				X												
59	F	X										ok					
60	G																
61	H													X			
62	F											X	X		X		
63	G																
64	F	X															
65	H											ok	X				
66	I				X					X							X
67	F											X	X				X
68	F									X		ok					
69	G																
70	G																
71	I			X													
72	I											ok	X			X	
73	I				X												
74	I			X													
75	F	X															
76	I											ok				X	
77	I											ok	X				
78	I											ok	X		X	X	
79	I											ok			X		
80	F											X	X	X			
81	I											ok	X				
82	I										X	ok					
83	I											ok	X			X	
84	I											ok	X				

FTO	Pack Config.	Air Bottle	Nose Tuck	Line Entanglement	Line Failure	Premature Wing	Riser Twist	Riser Failure	Gusset Failure	Air Loss	Reefing Cutter	Remote Control	Homing	Late Wing	Flt. Control Sys.	Broken Antenna	Line Lengths	Receiver	Tube Test	Riser Connec.	High Tumble Rate	Switch not "On"
85	I											ok										
86	I											ok	X		X							
87	I											ok										
88	I	X																				
89	I											X	X									
90	I											ok										
91	I											ok										
92	I	ok																				
93	I											ok	X									
94	I											ok	X									
95	I											X						X				
96	I								X	X												
97	I								X	X												
98	I	X										ok										
99	I	X										ok										
100	I																		X			
101	I			X								ok										
102	I			X		X																
103	I				X	X				X		X										
104	I			X								ok										
105	I											ok										
106	I				X																X	
107	I	X																			X	
108	J									X		ok									X	
109	J											ok										
110	J				X							ok										
111	J	X																				
112	J											ok										
113	J											ok										
114	J											X										
115	J	X																				
116	J			X																		
117	J			X																		
118	J											ok										
119	J											ok										
120	J			X																		
121	J																					
122	J									X												
123	J											X									X	
124	J									X												
125	J			X										X								
126	J				X					X												
127	I											ok										

FTO	Pack Config.	Air Bottle	Nose Tuck	Line Entanglement	Line Failure	Premature Wing	Riser Twist	Riser Failure	Gusset Failure	Air Loss	Reefing Cutter	Remote Control	Homing	Late Wing	Flt. Control Sys.	Broken Antenna	Line Lengths	Receiver	Tube Test	Riser Connec.	High Tumble Rate	Switch not "On"
128	I											ok										
129	I			X																		
130	I											ok	ok									
131	I											ok	ok									
132	I											ok	ok									
133	K				X																	
134	I			X																		
135	I											ok	ok									
136	J											ok	ok									
137	L											X	X	X								
138	K											ok	ok									
139	L											X										

TABLE 8

SUMMARY OF PARAGLIDER PERFORMANCE FROM REDUCED CINE-THEODOLITE DATA

Flight Test Operation	L/D	Average True Airspeed (Feet/Second)	Average Rate of Descent (Feet/Second)	Average Maximum Rate of Turn (Degrees/Second)	Average Minimum Radius of Turn (Feet)
9-101-6	2.78	43.6	15.7	9	250
20-101-12	3.24	48.7	15	12	200
52-103-18	2.40	30.7	12.8	4.4	400
77-104-12	2.91	37.0	12.7	7.5	300
84-104-15	3.1	41	13.0	10	200

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